SATELLITE IMAGERY FOR • THE MASSES

How to Use and Profit from the Satellite Revolution

HAROLD HOUGH

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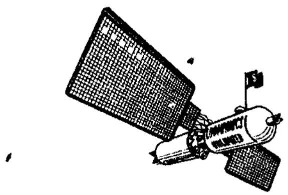
By Harold Hough



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Contents

To Nancy

Without whose love, support and persistence, this book would have not been written.

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I also want to acknowledge my friend and professional colleague, Ernie Ross, who unfortunately died just as I was beginning this book. It was Ernie who accepted my first article that used satellite imagery and continued to encourage me through the years. He will be remembered and missed.

A special thanks goes to Michael Patrick and the Christian Broadcasting Network News (CBN News) who were pioneers in the use of satellite imagery in investigative reporting. Then there are the satellite imaging companies, Space Imaging, SPOT, DigitalGlobe, Autometric, and Sovinformsputnik, who kindly allowed me to use their imagery in this book.

And a heartfelt thanks to the friends who gave me moral support and patiently listened to me babble endlessly about satellites while I wrote this — Rob, Dave, Lowell, Lavorris, Bill, Bob, Erwin, Melissa, and Marv. I'll try to talk about something else now.

And, finally, a thanks to Enzo, my cat and self-appointed editor, who sat in my lap the whole time I wrote this and made corrections as necessary.

Chapter One
Introduction

Imagine designing a computer game that shows exactly how it looked to American military pilots as they flew over Hanoi during the Vietnam War. Or getting paid by a news agency to find a top secret North Korean weapons facility. Imagine owning your own consulting business where you help other businessmen decide where they should place their new businesses. How about making a little money on the side finding a good placer gold deposit or antiques along an old pioneer trail? These are all possible today because of the availability of satellite imagery to the average person.

The last fifteen years have been to commercial satellite imagery what the 1980s and early 1990s were to computers. What was once technology limited to scientists is now found on the main streets of America. Everyday people like real estate agents, police, marketing experts, and journalists use satellite imagery on an everyday basis. In fact today, there are people using satellite imagery in their jobs that once thought

SPOT was something you found on a dress, not a satellite in space.

Today, satellite imagery is used in courts as legal evidence, by earth resources companies to find minerals, by environmentalists to find pollution, by historians to better understand history, and by civil engineers to build infrastructure. It is even being used by the government to tax you and find zoning violations.

There is no better example of how commercial satellite imagery has matured as an industry than what happened in the last two wars in Iraq.

In August 1990, the 82nd Airborne Division had a problem. They had been deployed to Saudi Arabia to stand between an Iraqi Army poised to attack and the Saudi oil fields. These few thousand lightly armed troops only had days in which to move their equipment across the treacherous sands of the Saudi Desert and into position where they could defend the oil fields against the fourth largest army in the world.

Without heavy weapons, the units could rely on only two factors to stop the Iraqi juggernaut: professional, trained soldiers and high tech equipment. But, moving soldiers and equipment was difficult because the soft desert sand could trap and disable the vehicles as effectively as an Iraqi minefield. At the same time, the available maps of Saudi Arabia were more than a quarter century old. If the allied forces were to confront the Iraqis, they would need accurate maps immediately.

Because traditional map making took months, the Army used commercial satellite imagery and the Global Positioning System (GPS). In addition, when air operations started, military pilots used commercial satellite imagery to plan and "virtually" fly through missions.

By the 2003 Iraqi war, commercial satellite applications had blossomed. For months before the operations began, government agencies were buying commercial satellite imagery every time imaging spacecraft flew over the Middle East. In addition to maps and training for air missions, commercial satellite imagery was used for bomb damage assessment, producing maps for units, looking for weapons of mass destruction, tracking Iraqi units, and following any damage caused by Saddam's henchmen.

But satellite imagery wasn't just the purview of the government and military. It was widely used by news agencies and analysts for following the war. Viewers were given virtual three-dimensional "fly throughs" of Baghdad, Basra, and any other area of interest. News groups followed suspected areas, where weapons of mass destruction might be manufactured or stored, they reported on Saddam's palaces, and pointed out other potential targets with regularly updated satellite imagery.

One such target was Baghdad International Airport. Even as U.S. forces were fighting for the airport, Space Imaging released IKONOS satellite imagery of the deserted airfield that was taken less than 48 hours before U.S. forces arrived on the scene.

While most of the television news groups showed this satellite imagery of the airport, they tended to view it just as "eye candy," something to stimulate the viewer's eyes rather than being a critical part of the story. If, instead, they had looked at the image for news value, they might have noticed a lone Russian transport aircraft parked next to a warehouse. This begs the question, what was a Russian transport doing at a deserted Iraqi airport just hours before being captured by Americans? What were they bringing in or taking out?

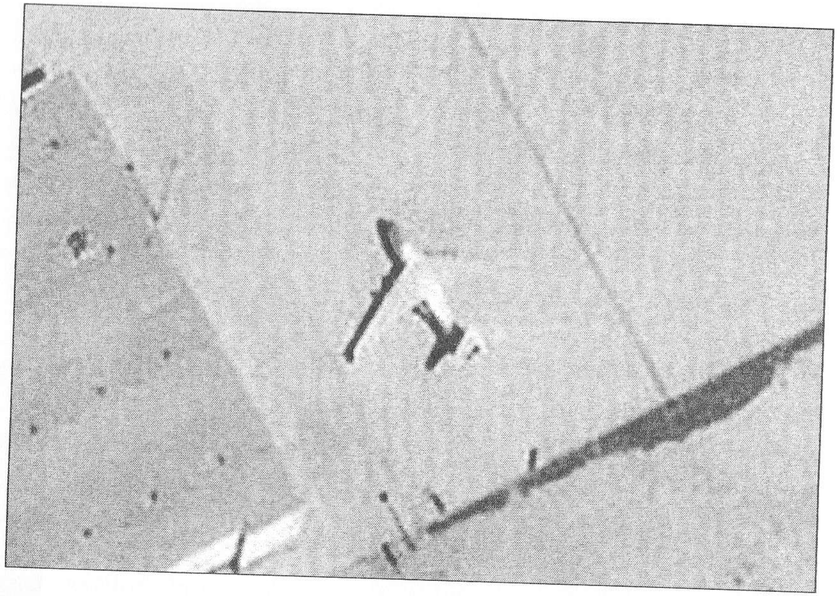

Figure 1.1
What was a Russian transport aircraft doing in Baghdad just two days before the airport was overrun by American forces? (Photo courtesy of Space Imaging)

This glaring mistake by the major news groups proves there is still a place for the average person who wants to make some money in this new, exciting industry. There is a lot of imagery out there, and unfortunately, it isn't being exploited as well as it could be.

Fortunately, prices of satellite imagery have plummeted in the last decade. In the early 1990s, medium resolution French or Russian satellite imagery cost thousands of dollars per scene and took months to get delivery. Today, a better product is available for a few dollars per square kilometer. You can

buy it online with your credit card and get a digital image delivered immediately via e-mail.

At the same time, satellite imagery quality has become better. When my book *Satellite Surveillance* was written in 1990, the best available commercial satellite imagery could only see an object as small as 15 feet in diameter. Today, commercial satellites can see objects as small as two feet in diameter! That has opened up new applications that are awaiting someone bold enough to develop them.

While my previous book was written to explain how satellite imagery works, this book is written to show you how to use it for yourself and even make money. Thanks to the proliferation of commercial satellite imagery, the low prices, the availability, and the high quality applications, opportunities for the average person are greater than ever before. Here are some of the areas this book will look at:

Virtual Three-dimensional Satellite Scenes. Ten years ago, this took hundreds of thousands of dollars in software and computers. The only group who could afford to use it regularly was the Defense Department, which used it to help pilots practice bombing runs and special operations insertions.

Today, you need an average desktop computer, inexpensive (or even free) software, and satellite imagery. You can make a computer-generated scene that looks like you are flying over a top-secret installation like Area 51. If you are a police sniper, you can use three-dimensional satellite imagery to find the best view of a hostage situation and a clear shot. Or you can go back into history by using spy satellite imagery to recreate a military event from the Six Day War or Vietnam. The only limits are your imagination.

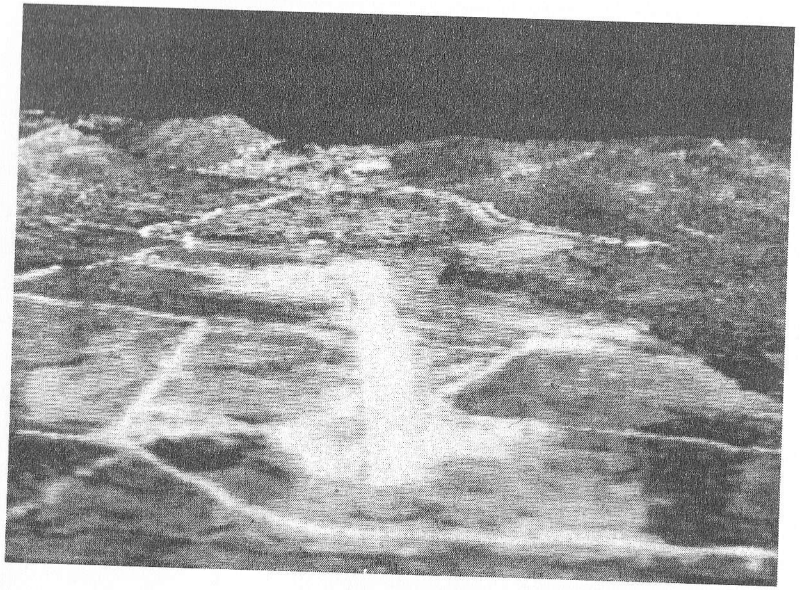

Figure 1.2
Three-dimensional satellite imagery like this was used to train military pilots for special operations insertions. They could virtually fly through an enemy occupied territory beforehand, which lowered the chances of mistakes during the real mission. (Photo courtesy of Autometric)

History. Did you know that the first ten years of spy satellite imagery is available for everyone to look at, providing you know how to find it? This book will tell you how it is stored at the National Archives, how you can copy it with your own camera, and how you can use it to study the Vietnam War, the Cold War, and the 1967 Arab/Israeli War. Game designers can use this imagery to make Vietnam War computer games more realistic. Historians can use it to better understand events.

But this old imagery isn't just for historians. For example, if you are a company that has been charged with recent pollution

violations, you would be able to use these photos as solid legal evidence that the pollution existed before you bought the site. We will also look at uncovering declassified U-2 aerial imagery and intelligence imagery from World War Two.

Military Affairs. There are more secret military facilities than photo interpreters to look at them. Just as that Russian transport was missed in Baghdad, a military affairs amateur can find something interesting somewhere in the world.

Commercial Ventures. Everything from mapping towns to real estate, to finding a new location for a new store can benefit from satellite imagery. And, since most people don't know how to exploit it, an average person with a little special knowledge can help make it available to them.

Investigative Journalism. Is Iran completing its nuclear reactors at Bushehr? Where does Syria keep its Scud missiles? Where do the Israelis store their nuclear weapons? What is the state of North Korea's nuclear program? All these stories can benefit from satellite imagery. In fact, in December 1991, ABC News was poised to join the ranks of the great military powers by buying its own high-resolution spy satellite. At the time, ABC executives were in Moscow negotiating with cash-strapped Russian officials for the sale of one of their reconnaissance satellites. Unfortunately, negotiations broke down when the Russians asked for $800 million. As one defense analyst said after learning about the asking price, "The Russians don't really understand capitalism yet."

This book has a complete section that gives journalists or anyone else who wants to do some investigative work, the key to finding critical military facilities. Sample pictures are shown for everything from nuclear reactors, to weapons bunkers, to missiles and ships. Most of these are very recent and many come from recent events in the Middle East. This sec-

tion may provide just enough of an edge to win a Pulitzer Prize.

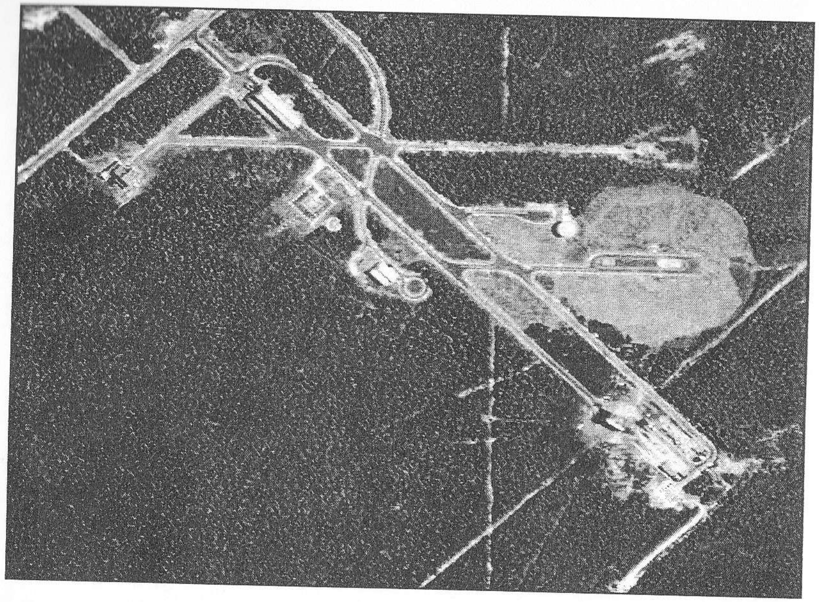

Figure 1.3
The Brazilian space facility at Alcantara. Just days after a rocket blew up on the launch pad in August 2003, this picture was taken by Space Imaging. Note the scarring in the lower right hand corner. As you read this book, you will learn to identify many of the features in this image. (Photo courtesy of Space Imaging)

Prospecting. The major mining companies are using satellite imagery for prospecting. Why not you? If you are one of the many amateur gold prospectors in America, you might want to take a look at satellite imagery. In an afternoon you can cover thousands of square miles looking for likely placer

gold deposits, far more than you could ever do in a lifetime of traditional prospecting.

Archeology. Did you know that modern satellite imagery has been used to find everything from Indian villages to sunken ships, and ancient cities? You may not be Indiana Jones, but you can still find some adventure, fame, glory, and even a little money discovering antiques and other collectables in America's West.

Personal Interests. Is that piece of property you are looking at in a flood plain? Are there potential terrorist targets in your vicinity, and how would an attack on them affect you? Does everyone else in your neighborhood have a swimming pool? Where would be a good place to hunt for quail? A quick look at some satellite imagery can answer your questions.

One final warning. I know that I'm trying to cover a lot of material and leaving out some of the details. My goal is to write a book that everyone, not just satellite experts, can read, understand, and use. If, after reading this book, you can make informed decisions on how to profit from satellite imagery, I was successful. If you want more information on the science of satellite imagery, I suggest you read my book *Satellite Surveillance*. In the meantime, I hope you enjoy reading this book as much as I enjoyed putting it together.

Chapter Two
A Brief History of Satellite Imagery

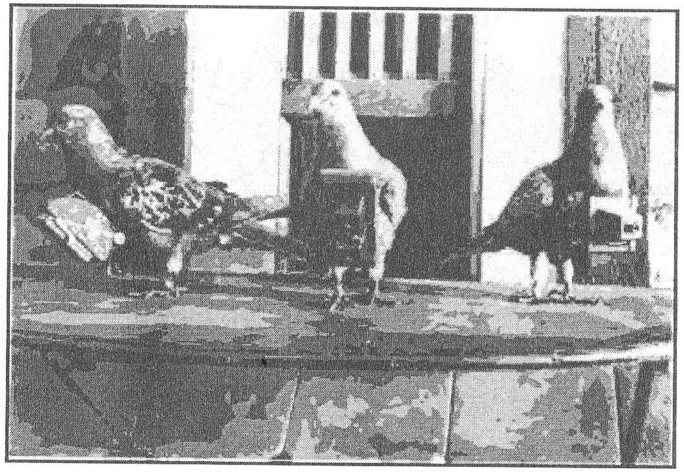

Figure 2.1
Obviously earlier overhead imaging systems were unable to operate effectively in space. (NASA)

Although we could go back beyond the space age to look at the antecedents of satellite imagery (aerial imagery, carrier pigeon photos, etc.) and we could write a whole book on the subject, let's cut to the chase. In this case, we will start with the space race between the U.S. and Soviet Union.

Although the use of rockets as a camera platform was first proposed in 1891, the first photos from space were actually taken in the 1940s, after World War Two. The vehicles for these fledgling space images were confiscated German V-2 rockets, which provided the basis for the Russian and American post war rocket programs. Not only did these missiles provide the foundation of both the American and Russian ICBM programs, they were instrumental in the first studies of outer space.

Figure 2.2
America's Viking 12 was launched from White Sands, New Mexico in 1946. This picture shows Arizona and California. (NASA)

The American V-2 program was called Viking and was centered on the 250 V-2s and supporting equipment captured by the U.S. during Operation Hermes. (Operation Hermes was the American operation to get advanced German technology out of Germany at the end of the war.) The Viking project began in 1946 at White Sands Proving Ground, New Mexico. This U.S. Army sponsored project launched at least 62 of the German vehicles (although less than half that number was successful). Of those, some reached into the upper atmosphere and into what is now considered space. On board several of the vehicles were still and motion picture cameras that took photographs as the rocket ascended into space.

As dramatic as the photos were, they had limited use because they were usually oblique shots that only covered areas near the rocket launch site. It wasn't until the late 1950s, when orbiting spacecraft were finally placed in space, that one space vehicle could acquire imagery from many parts of the planet.

Despite the rush by the military and intelligence agencies to get a spy camera in space, it was a civilian application that ranks as the first use of satellite imagery. On April 1, 1960, TIROS-1 (Television Infrared Observation Satellite) was launched into space. Its mission was studying cloud formations and it was the first "real time" satellite, in that it could send its data back to earth on a nearly immediate basis. The problem was that the television cameras of that day had poor spatial resolution and the smallest object the satellite could detect was 100 feet in diameter. This was too poor for traditional photo interpretation, but the Air Force was interested because this was the era of massive nuclear-armed bomber fleets and the Strategic Air Command needed reports on cloud formations and weather reports over the USSR.

Photo interpreters got their satellite imagery with the Discoverer series of satellites. Although billed as a scientific program, Project Corona (as it was known in the intelligence community) was a spy satellite program. The satellites were designed to acquire high-resolution photographs of the Soviet Union and then eject their film canisters into the Pacific Ocean. While the film canister was parachuting down, an Air Force plane would supposedly recover it in mid air.

Launching a satellite and recovering a film canister proved harder than originally thought. The first twelve missions were failures, although Discoverer II did successfully eject its film canister near the Norwegian/Soviet border. Discoverer XIII did succeed, but its payload was a set of sensors that recorded Soviet radar emissions.

Discoverer XIV (Mission 9009) was a complete success and the recovered film canister was rushed to Kodak Labs in Rochester, New York (this would be considered a true Kodak moment). Since film had never been recovered from space before, the experts were concerned that the images might fade soon after developing. Consequently, a CIA photo interpreter was stationed at the end of the developing machine to give a quick interpretation. Fortunately, the images didn't disappear and the interpreters had pictures of the Mys-Schmidta air base and the ICBM base at Plesetsk to study. The resolution was poor, only about 50 feet, but to Andrew Goodpaster, they were, "like the dog that walks on its hind legs, remarkable that it happens at all."

Although the first satellite imagery was poor compared to U-2 imagery, it got better as time went along. When the KH-2 system was launched, resolution was 25 feet. Just a couple of years later, resolution was six feet thanks to the improved optics of the KH-4B system.

While the KH spy satellites were critical to the Cold War, they also laid an important cornerstone to future commercial applications. The KH-3 system was the first to use stereo cameras, which allowed for three-dimensional analysis. KH-5 was primarily a mapping system (ARGON), which was used to develop the accurate maps needed for targeting ICBMs. It set a new standard for map making. And in 1970, the CIA investigated the use of color satellite imagery for mineral exploration.

Despite the successes, there were the glitches and humorous moments like the squashed bug found in the film emulsion, exactly where a secret Soviet facility was supposed to be. There was also the time that the positioning cameras showed a silver sphere in space (no, it wasn't a UFO, but a weather balloon that managed to reach the lower borders of outer space).

Since they were advancing the science of photo interpretation, these photo interpreters for the CIA were soon used for other tasks like analyzing photos of world leaders or secret Soviet equipment. Ironically, one of the biggest tasks that required photo interpretation, analyzing a Russian submarine, which sunk off Hawaii in the late 1960s, was kept from these experts. Although the U.S. Navy had taken photos of the sunken sub with a remote controlled submersible camera, they weren't given to the National Photographic Interpretation Center (NPIC) for interpretation. Instead, Art Lundahl, the legendary head of NPIC created a special taskforce of two interpreters in Maryland who worked on the photos and reported directly to him. No one else at NPIC was aware of the Russian sub or the attempt to recover it from the bottom of the ocean by the Glomar Explorer.

Russian Satellite Imagery Development

Although the United States put spy satellites in space first, it didn't take long for the Soviets to catch up. On April 26, 1962, they launched Cosmos 4 on a Vostok rocket from their launch center at Tyuratam in Central Asia. About a week later, the camera pod came down. The resolution was poor and not good enough to count or analyze American military hardware. However, it could easily see objects like roads, buildings, and rivers, which made it adequate for mapping and targeting strategic American targets.

What followed was a highly successful spy satellite program that evolved differently than the U.S. spy satellite program. Since U.S. society was open, the Soviets didn't have the critical need for satellite imagery, so there was less priority on the project. Their satellites were larger and less miniaturized since the Russian lead was in large boosters. This also gave them the opportunity to make use of world-class film and lenses from their East German allies and Zeiss of Jena.

The second generation of Soviet spy satellites were much improved and launched from Plesetsk into a polar orbit. Ironically, the U.S. was unaware of their purpose until a British schoolteacher, who tracked satellite orbits for a hobby noticed their different orbit and determined their purpose.

These new satellites fell into three categories, high resolution, low resolution, and maneuverable satellites. While the low and high resolution satellites stayed up for eight days, the maneuverable satellites remained in space for 12 days. This generation of satellites continued to stay in use until the Fall of 1983, when the third generation satellites were launched. The

new class of satellites were all maneuverable and remained in orbit for 12 days. However, they were separated by the optics: high, medium, and low resolution.

Although Soviet photographic systems were world class, they wanted electronic imaging that gave them real time imagery. However, they had fallen far behind the U.S. in electronics by the late 1970s. Since photographic imagery still offered the best resolution, the fourth generation spy satellite still produced high-resolution photographic products, although a low resolution TV camera was onboard. In order to get up-to-date information, they relied on frequent, timely launches of their spy satellites.

In order to keep a lead in resolution, the Russians used the highest resolution black and white film. They obtained color images by using a bank of cameras and special filters that looked at specific bands of light. The negatives could later be matched to provide "color" images.

Russia finally solved the electronics problem on March 29, 1984, with the launch of Cosmos 1546. It was the Soviet equivalent of the KH-11 in that it gave "real time" imagery. However, it reflected several compromises due to the fact that the Russians had fallen behind in both the space and electronics race. First, since it wasn't launched by a major rocket booster like the American Space Shuttle, the satellite was smaller. And, since Soviet solid-state electronics weren't as good as American electronics, the satellite's capabilities were limited. It only had a one-dimensional array of light detectors, which collected imagery as it swept across the terrain, much like a broom sweeps over the floor. It also had fewer shades of grey in order to limit the amount of data that had to be relayed back to earth.

Cosmos 1546 was maneuverable and could change its orbit from 200 to 400 kilometers in altitude. It had a focal length of 1.375 meters and a resolution of about 2 meters. In order to maximize resolution, it only transmitted black and white images.

The Soviet satellite had many weaknesses. The width of the scene was only 16 kilometers, which kept it from looking at large areas. The poor Soviet space communications capabilities meant they were unable to transmit as much data. Like its American counterpart, the Soviet satellite had a thermal infrared sensor, which could see in the dark, but it was considerably worse than the American system, which meant the Soviets were usually blind when their satellites traveled over the dark side of the Earth.

The Soviets continued to rely on photographic systems. The highest resolution imagery was still provided by traditional cameras, while low-resolution cameras, calibrated especially for mapping, photographed large areas.

Although the Russians remain behind the West in satellite imaging technology, the end of the Cold War has allowed them access to more Western technologies. As we will see in later chapters, the Russians are still in the satellite imagery business and a good source for some imagery, especially high quality photographic products.

The Evolution of Commercial Satellite Imagery

Commercial satellite imagery has always been the poor stepsister of the military reconnaissance systems. Since space was an expensive endeavor, few companies could afford the high cost of launching a commercial imaging satellite, especially since their capabilities were severely limited by the intelligence community. That's why most of the 100 or so commercial satellites are involved in communications.

The decision to restrict commercial satellite imagery was made in the early 1960s, when President Kennedy created an interagency committee to study the political aspects of America's spy satellites. One of the suggestions of the committee was to limit civilian satellite spatial resolution to no less than 98 feet. The recommendation was accepted and for several decades the U.S. LANDSAT satellite program was limited to that resolution. It wasn't until the 1990s, when the French and Russians began to dominate the space imaging industry, that American companies were allowed to compete.

Ironically, the limitations on resolution forced the commercial satellites to focus on what is called multispectral imagery. Rather than just look at visible light (red, green, and blue), the sensors began to look at other parts of the electromagnetic spectrum like near infrared and thermal infrared (for more information on multispectral imagery, please refer to my book *Satellite Surveillance*). These different bands of electromagnetic energy were discovered to have special applications in earth sciences, so the U.S. initiated the Earth Resources Technology Satellites Program (ERTS) in 1967. The first satellite, ERTS-1 was launched in 1972, onboard a Nimbus weather satellite. The success of the ERTS program led to the launching of several more satellites, now called LANDSAT.

The success of multispectral imagery had an effect on the American intelligence community. Several voices in the CIA argued for more spy satellite missions with color and infrared film because they could detect objects that were invisible to traditional panchromatic film. Unfortunately, these voices were usually in the minority and most missions continued to

use higher resolution black and white film, which usually had about twice the ground resolution.

In the early days, civilian satellite images were used nearly exclusively by government agencies and the scientific community. Private industry was slow to use satellite imagery because few business leaders could understand the imagery and the often complex science behind it. For instance, when geologists began to show mining executives that multispectral imagery could aid in mineral exploration, they were skeptical. Although executives understand cash flow and return on investment, they were lost when a geologist tried to explain how looking differently at red, green, blue, and infrared light can find a mineral deposit. It didn't help that satellite imagery was expensive at the time, too.

By the 1980s, the American monopoly on satellite imagery was breaking up. In 1986, the French launched the SPOT satellite (Satellite Pour l'Observation de la Terra). It could see visible light and near infrared. Best of all, it had a spatial resolution of 10 meters, which opened up more civilian applications.

Ironically, the end of the Cold War, which inspired the race for space imagery in the first place, brought in a new player: the Russians. Post-Soviet Russia, which was in desperate need of hard currency, decided in the early 1990s to sell the product of their spy satellites. At first, they offered 10 meter resolution and 5 meter resolution imagery from two of their reconnaissance satellite systems. Later, they changed the standard of high resolution satellite imagery by offering 2 meter imagery from their KVR-1000 satellite system.

By now the floodgates on space imaging had opened up wide. Soon, other countries like Japan, Brazil, India, the European Community, and Canada started putting sensors in orbit.

Many times they were just part of the payload on a space shuttle mission, other times they were a separate satellite. But, however it was done, there was a growing archive of satellite imagery of the Earth.

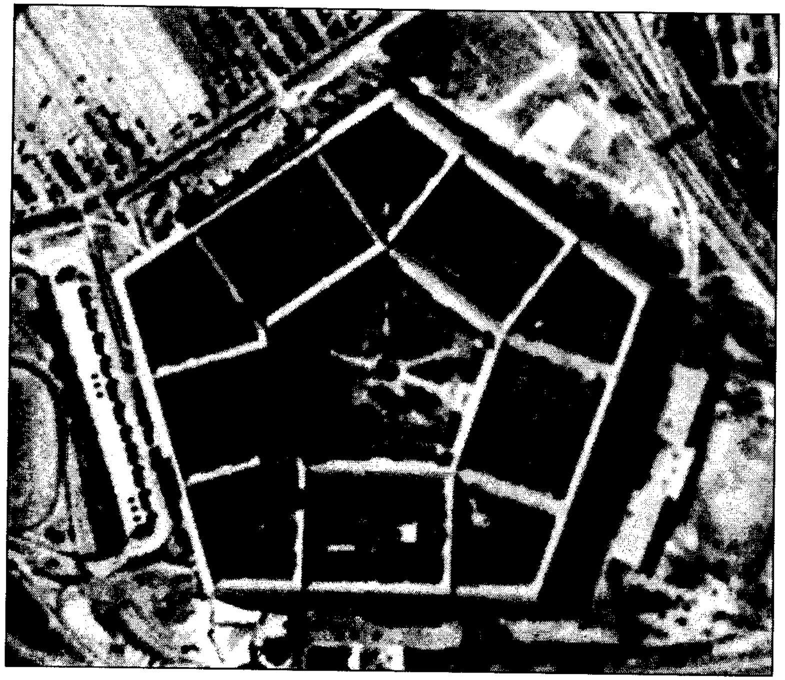

Figure 2.3
The first high resolution imagery reaches the civilian market. This two-meter resolution image of the Pentagon was a sample circulated by the Russians to interest potential clients. (Sovinform-sputnik)

It was obvious that the U.S. government couldn't control the resolution of satellites in space any longer since so many

countries, especially the Russians and French were in the business. As a result, the U.S. government deregulated the industry, while maintaining several restrictions concerning national security and satellite coverage of Israel. This allowed the U.S. space industry to do what it does best and in 1993, the U.S. Department of Commerce granted the first license to build and operate a high spatial resolution digital imagery satellite for commercial purposes.

Figure 2.4
The pioneer of commercial satellite imagery. This image of a Soviet airfield at Mys Shmidta is the first image taken from an orbiting satellite. (Central Intelligence Agency)

The first satellite to successfully take advantage of this new policy was IKONOS, which was the first commercial satellite with one-meter resolution. The 1,600 lb. satellite orbits the earth every 98 minutes at 423 miles. The orbit is sun-

synchronous, which means that it passes over about 10:30 am local time. This is early enough in the day that heat doesn't degrade the atmosphere too much. It also offers some shadows so analysts can measure the heights of objects on the ground.

However, the race for the best space-based sensor isn't over. The best spatial resolution satellite, as this book is being written is Quickbird 2, which was launched in October 2001 and boasts a resolution of 2 feet. And, lest multispectral imagery is forgotten, scientists are looking at hyperspectral imagery, which records hundreds of distinct parts of the electromagnetic spectrum. This will be a boon for earth resources scientists, because they will be better able to determine the exact chemistry of an area, just by studying how light interacts with the various chemicals in the ground.

The growing satellite business also had a beneficial effect on the U.S. government's obsession with secrecy. When it became obvious that the world wasn't going to fall apart with the availability of high-resolution satellite imagery, the Clinton Administration ordered the declassification of imagery from the nation's first spy satellite program (CORONA). Today, anyone can go to the National Archives outside Washington, DC, or the EROS Data Center in Sioux Falls, South Dakota, and acquire this top secret satellite imagery that was so critical during the Cold War.

Summary

Commercial satellite imagery has advanced dramatically in the last fifteen years. Unlike the first 25 years of space imaging where the military and intelligence communities benefited, most of the recent improvement has come in commercially available imagery, which has finally been released from the

artificial restrictions of intelligence guidelines. Today, there is a wide assortment of satellite imagery for a wide range of prices. And, as we will see later in this book, there are many applications that have hardly been touched.

Civilian Satellite Imagery Programs

This is a list of civilian satellite imagery programs that have actually successfully launched a satellite. Some like LANDSAT and RESURS have launched many vehicles over the years. At the same time, the imaging systems have improved, which has allowed better spatial resolution and coverage of more spectral bands. No wonder keeping track of satellite imagery can be confusing.

Program	Country
LANDSAT	U.S.
SEASAT	U.S.
HCMM	U.S.
RESURS	Russia
IRS	India
ERS	Europe
JERS	Japan
RADARSAT	Canada
ADEOS	Japan
TERRA	U.S.
Nimbus	U.S.
SPOT	France
Orbview	U.S.
SPIN-2	Russia
IKONOS	U.S.
Quickbird	U.S.
EROS	Israel

Chapter Three
How Satellite Imagery Works

In the last chapter you read the phrase, "spatial resolution." You may have even wondered what it meant. Well, thanks for hanging in there because we will now talk about resolution.

The normal definition of resolution is the smallest object something (either a camera, photographic film, or spy satellite) can detect. In the case of the last chapter, when we talked about a satellite having a resolution of one meter, the smallest object the satellite could detect was one meter in diameter. Note that I said "detect" not identify. The object could be a pile of dirt, or an engine block, but you couldn't tell from the satellite image. Of course, the surroundings can give you a good hint. For instance, if you were viewing a construction site, it would be more likely to be a pile of dirt than an engine block. Of course, it could just as easily be a stack of bricks, too.

Now that I've given you the easy definition, let's make it complicated. For the purpose of this book, we will talk about two types of resolution: spatial resolution and spectral resolu-

tion. Spatial resolution, as we just talked about is the smallest object that you can detect. Spectral resolution involves ability to detect smaller segments of the electromagnetic spectrum.

Here's an example of the differences between spatial and spectral resolution. Kodak produces a black and white film called Panatomic X. It is used by professionals who want the highest spatial resolution because they want to enlarge their photographs. It can differentiate up to 300 lines per millimeter (meaning that it can record something as small as .0033 mm in diameter on the negative). However, it has poor spectral resolution because it records visible light as either black or white; there is no differentiation between greens and reds.

A color film, on the other hand, may have a worse spatial resolution of .01 (one hundred lines per millimeter), but will record red, green, and blue, and also many shades in between. What it loses in spatial resolution, it more than makes up for in spectral resolution.

The same is true with satellite imagery. Just as some want the maximum resolution and are willing to trade color for it, there are some who will need the highest spatial resolution satellite imagery available, even if it is just black and white (called panchromatic by professionals). Others need more spectral resolution because they need to study objects like plants where the spectral information is critical.

With these basic definitions in mind, let's continue.

Understanding Spatial Resolution

Despite all the previous talk about the importance of spectral information, the benchmark for imaging satellites is still spatial resolution. When a new satellite is launched everyone says, "I hear that SuperBird I was launched yesterday. It has a

resolution of 45 centimeters." I have yet to hear anyone say, "I hear that SuperBird I was launched yesterday. It has a spectral resolution of one nanometer in the shortwave infrared band." Well, okay, there are probably a few nerdy scientists who get excited about things like that, but they are few in number. In reality, satellite spatial resolution is like a processor speed or accelerating from 0 to 60 mph in x number of seconds for cars; the standard everyone tries to better.

Unfortunately, there are a lot of factors in spatial resolution that you have to understand. The final resolution figure that the satellite manufacturers brag about is a function of the sensor size, optics, and the satellite's orbit.

Lest you think that these new high resolution satellites are something special, let's compare them to readily available camera equipment. The formula for determining resolution is: Resolution = (Distance/Focal Length) x Resolution diameter. Resolution diameter is the size of the light-sensing element in the system, whether it's a charged couple device (CCD) or the grain size of the silver compound in the film. In the case of high resolution professional films, the resolution is over 300 lines per mm.

Using the formula above, let's see what the resolution of a satellite could be if we used readily available camera equipment. If we put a 35mm camera on a satellite that had an orbit of 150 kilometers and used a commercially available 1,000 mm lens and Kodak Technical Pan film, the equation would look like this: (150 km/1,000mm) X .000003mm = .45 meters. That means commercially available equipment costing about $1,000 could see something the size of a newspaper on the ground.

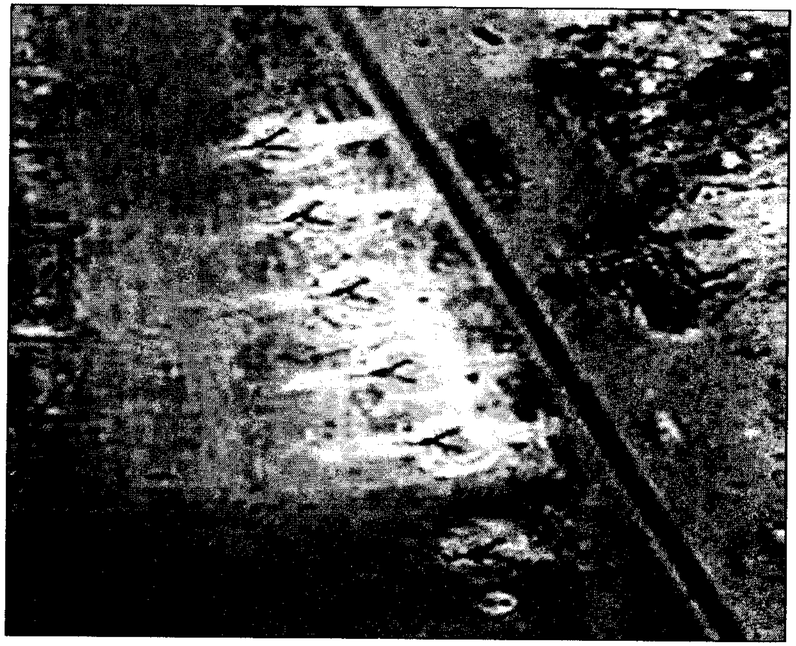

Figure 3.1
How good is one-meter resolution satellite imagery? Here is a battery of Syrian Howitzers near Homs, Syria. (Space Imaging)

I know what you are thinking. If commercial cameras are so good, why do we have expensive spy satellites? We can just send up a camera with the astronauts and develop the film at the local Wal-Mart. Good question. The fact is that many manned space missions are primarily Department of Defense missions and the astronauts do use commercially available cameras to take snapshots out of the window. However, keeping an astronaut up in space with a 35mm camera is much more expensive than a fully automated satellite imaging system.

Of course, there is more to acquiring high spatial resolution imagery from a satellite than picking up some camera equipment from the local mall. Obviously, distance from the object means a lot. The 150 km orbit used in this example is quite low and the satellite would reenter the atmosphere in a short time. However, that is what the early spy satellites did. Today's imaging satellites cost hundreds of million of dollars and in order to recoup the investment, long orbital lives, and subsequently higher orbits are required.

Another factor in resolution is the size of the light-detecting device. Obviously, high-grade photographic film has a smaller size grain than the smallest CCD. Of course, silver film can only be used once, while CCDs can be reused again and again. In addition, while photographic film only uses about 2 percent of the light that strikes it, a CCD can convert over 80% of the light into a signal. That means it can be used in low light, which explains why a modern video camera or digital camera doesn't need additional light in dim light situations where a conventional camera would need a flash attachment.

There are also other factors, not mentioned by the satellite manufacturers that have an impact on the final resolution of a scene. For instance atmospheric conditions like smog, humidity, and cloud cover will obviously have an effect on what you can see. And, there is contrast. While a small mirror lying on the ground on a sunny day will be easy to find from space, because it stands out from the background, a polar bear in a snow field will be hard to detect with a high spatial resolution satellite imaging system. That's why spectral resolution is so important.

Spectral Resolution

While a high spatial resolution camera may have problems finding that polar bear on a snow field, the high spectral resolution system will have an easier time. For instance, while snow is cold, the bear, being a warm-blooded mammal will actually radiate heat and be detectable to a thermal infrared sensor. Snow is also made up of ice crystals, which also reflect more light than the bear's fur, so although both are white, the snowfield will reflect more sunlight than the bear's fur.

Humans also use spectral resolution in everyday events. For instance, you enter the kitchen and see the electric coils on your stove glowing a dull orange. You immediately know that the element is hot because you know metal that glows orange is HOT! You then go over and turn the element off. Several minutes later you walk back in and see that the element is gray once again. However, instead of precipitously touching it, you wave you hand a couple of inches from the element to see if you can feel any radiated heat.

You have just used two spectral sensors and two parts of the electromagnetic spectrum. The first sensor was the eye, which told you that the heating element was hot enough to glow orange. That's using the visible part of the electromagnetic spectrum. When that sensor system didn't give you enough information a few minutes later, you employed your second sensor, the hand. That is using the thermal infrared portion of the electromagnetic spectrum.

For all the talk about spectral resolution, multispectral imagery, and hyperspectral imagery, scientists use the information and sensors in the same manner that you did in the kitchen. You determine the characteristics of what you are trying to detect and use the sensors that you have available. In

most cases, you are looking at something on the ground and determining how it reflects sunlight.

If you are trying to determine the health of a farm crop, you want to use the near infrared band because vegetation reflects solar infrared energy, especially when it is healthy. If the amount of infrared light being reflected were lower in one field than in others of the same crop, it would make sense to check out the field to see if there are any problems. Ironically, the plant's reflectance in the shortwave infrared region increases as it becomes ill.

If you have a satellite imaging system with a high spectral resolution, you can learn even more. Each type of plant has its own reflective pattern, and the plant's reflective pattern changes as the plants mature. With a higher resolution spectral image, you can better determine the type of crops, how well they are maturing, and when they will be ready for harvest.

High spectral resolution is also critical in mineral exploration. Although many minerals and rocks look alike to us, they reflect sunlight in radically different ways. With computer enhancements, geologists can identify different families of minerals. In some cases, the mineral may affect plants, so by looking at the infrared reflection of the plants on the ground, geologists can gain insight into the geology.

"So if high spatial resolution and high spectral resolution are both so good, why isn't there a satellite that offers both?" you ask. Good idea. However, physics limits what we can do.

There is a trade-off. What we can sense depends on how many photons (light particles) we can collect and detect. If you want high spatial resolution, you want a small sensor (remember the equation). The problem is that small sensors cover a smaller area, so they will collect a fewer number of photons.

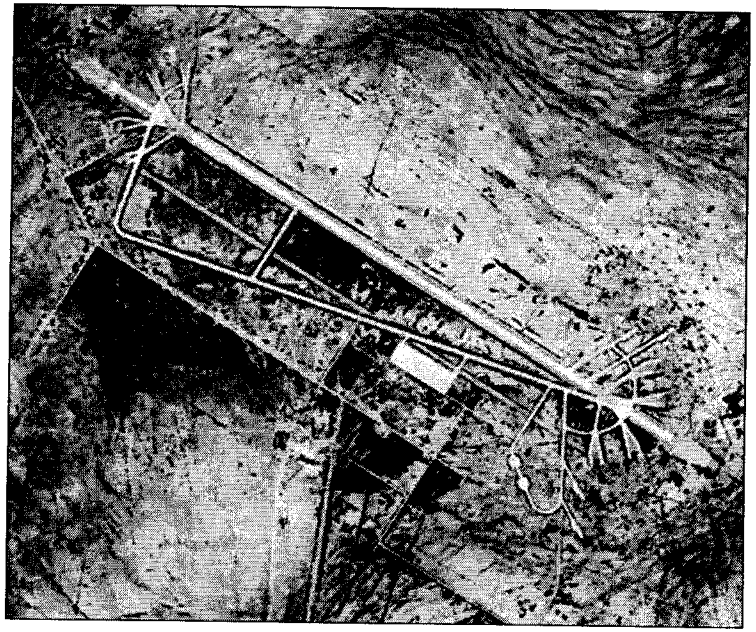

Figure 3.2

You don't need high resolution imagery to see that this is a military airfield. The revetments at each end of the runway are to protect fighters from air attacks. This airfield is in Western Iraq and was captured by U.S. Special Forces to prevent Scud attacks on Israel. (Space Imaging)

Suppose you want to build an imaging system that can gather high spatial and spectral imagery; one-meter spatial resolution and 20 bands of spectral information that covers everything from blue to near infrared. Sounds great! The problem is that in order to collect enough light to register in all twenty bands you need to collect more photons (a photon in the green wavelength, one in the red wavelength, etc.). Yet the size of the sensor is limited in order to keep the high resolu-

tion. It's like catching rainwater. You can use one big pail and catch a lot of rain or you can use smaller pails and expect to get a smaller amount in each pail. You can't use smaller pails and expect to get as much per pail as you did with a larger pail. The principle is the same as that of the human eye. In dark conditions, where there are fewer photons, the eye only detects black and white with its rods. Color vision is reserved for brighter conditions and the cones in the eye.

Most satellites have two types of sensors (just as the eye has cones and rods light sensors). One is a panchromatic sensor that collects all of the light and gives a high spatial resolution panchromatic (black and white) image. The other is a multispectral sensor that looks at several distinct parts of the electromagnetic band, but has poorer spatial resolution. When they are retrieved from the satellite, they are often blended by computer to give a color image that has the high resolution of the panchromatic scene. They are quite appealing to the eye, but the process of blending them does cause a loss of information. That's why professionals who rely on high spectral resolution want the separate bands of information.

Picking the Right Imagery for Your Purpose

If you feel confused, don't worry. There are a lot of satellite professionals who are confused by the rapid proliferation of spatial and spectral satellite imagery. However, you needn't be totally familiar with each type of sensor on every satellite. You just need to know what you need for your application. The fact is, several systems may meet your needs, and your final decision should be based on cost, availability of the infor-

mation you need, timeliness and the spectral resolution required for your purpose.

Although every satellite imaging system is slightly different, the sensors still fall in several large categories. Here they are:

Panchromatic. These are the high resolution satellite images that need to gather every photon of light to achieve the best resolution possible. Although each satellite's system will differ slightly, they generally collect all the light from the blue, green, red, and near infrared parts of the electromagnetic spectrum. (See Figure 2.3 on page 21 for an example.)

These panchromatic images are very popular with anyone looking at manmade objects or who are interested in civil engineering projects. They are less important in earth resources studies because they don't have the spectral information needed. However, they are often blended with multispectral imagery to give a sharp, color image.

Generally, the only reason for using panchromatic satellite imagery is to get the best resolution possible. Consequently, the poorer the resolution, generally the lower the price. If you don't need the best possible resolution or want to cover a larger area (generally the lower the spatial resolution, the larger the area covered), the best bet is to go with a lower resolution, cheap satellite image. For instance, if you want to make a road map of an area, it would make more sense to get a two or three-meter resolution image that will show roads, rather than a more expensive image that has two-foot resolution.

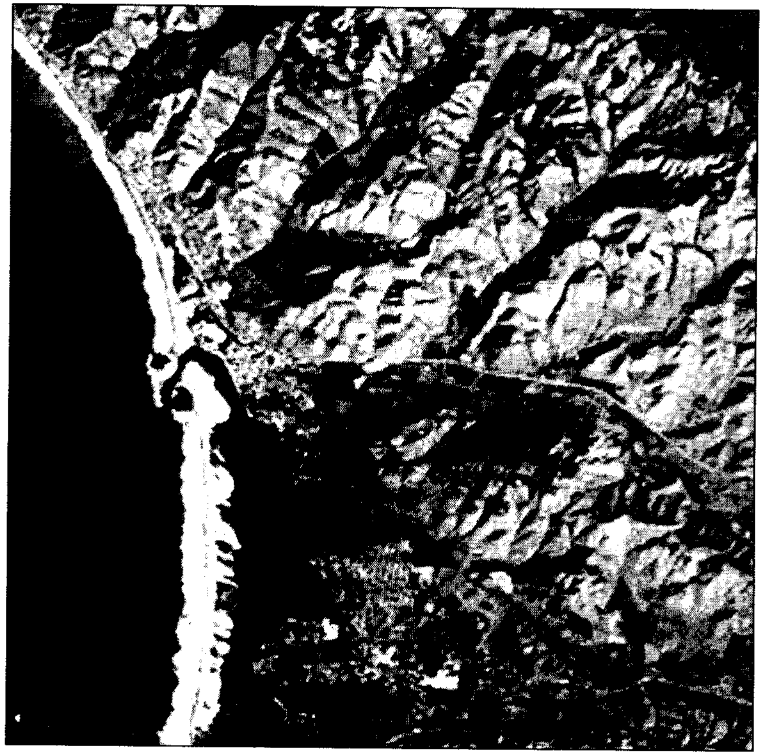

Figure 3.3
This is a panchromatic image showing green light from a coastal town. Note that water less than 90 feet deep is seen as a grey. (NASA)

Visible Light. This is the part of the electromagnetic spectrum that has a .4 to .7 micron wavelength. It's the only group of light that can see underwater and tends to scatter more than other bands like infrared. It is obviously broken down into three basic colors, red, green, and blue.

Blue Band. .4 to .5 micron wavelength. Blue light can penetrate up to 150 feet of water, so it is an excellent band

to study deep water. Of the three visible bands of light, it is the most likely to scatter in the atmosphere, which limits detail.

Green Band. .5 to .6 micron wavelength. Green light can penetrate up to 90 feet in clear water, so it can be used in conjunction with blue band light for water studies. It is also good for any project that looks at vegetation.

Red Band. .6 to 7 micron wavelength. This band of visible light scatters less than either green or blue, which provides more detail. It also penetrates up to 30 feet in clear water, so it can be used in conjunction with blue and green bands for underwater studies. Since it is the clearest visible band of light, it usually provides the best visible spectral information. (See Figure 6.3 on page 118 as an example.)

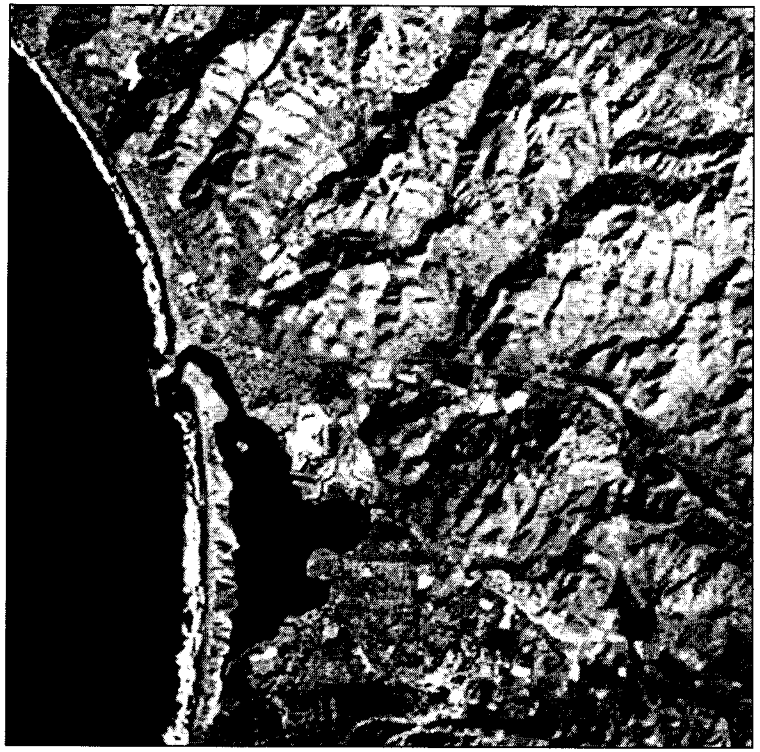

Figure 3.4

This near infrared image of the coastal town doesn't show any shallow water since water absorbs near infrared energy. The land is lighter, however, because healthy vegetation is reflecting the near infrared light. (NASA)

Near Infrared. .7 to .9 microns wavelength. This is the part of the electromagnetic spectrum that is best for vegetation studies because healthy plants reflect large amounts of near infrared energy back into space. This band is obviously important to finding camouflage.

Middle Infrared (also called shortwave infrared). 1.5 to 2.35 micron wavelength. This band can detect moisture content in ground, so it is excellent for real estate development, civil engineering, and transportation projects. Military planners use this band to see what problems they may have in moving heavy tracked vehicles like tanks across open terrain. This band can also detect hot objects like fires.

Thermal Infrared. 10.4 to 12.5 micron wavelength. This shows emitted heat energy instead of reflected energy. It can be used to detect water currents, geological structures, and manmade, heat-generating sources. Since the resolution is poor, its applications are limited.

Unless you are going to specialize in the select field of hyperspectral imagery, these general classifications should hold you in good stead. As a result of this general classification, there are only a few types of images that provide the most spatial and spectral information in an image. Some take one band each from visible, near infrared and middle infrared since that gives the broadest amount of information in one color image. However, the most popular imagers are:

True Color Image. This is the most natural image for anyone not used to viewing satellite imagery. It looks like what one would expect to see from a plane and is good for showing to people unfamiliar with satellite imagery. Since the evolution in high spatial resolution imagery, many satellite imagery providers blend their high spatial resolution imagery with a lower resolution color image to give the best of spatial and spectral resolution. (See Figure 4.1 on page 52 as an example.)

Infrared Image. This is a popular color image in vegetation studies. In it, one of the primary colors (blue, green, or red) is eliminated and infrared is substituted. Traditionally infrared has been displayed as red since red is closer to infrared and is

often associated with heat. However, since plants reflect infrared, many specialists use green for infrared because it highlights stands of vegetation. The choice is up to you. (See Figure 5.1 on page 66 as an example.)

If you aren't studying manmade objects or vegetation, the choice gets a bit harder. Here is a table of the best type of spectral bands for studying various features.

FEATURE	SPECTRAL REGION	COMMENTS
Clear water	2.08 to 2.35 microns	This band of energy is absorbed by water and gives a clear demarcation between land and water.
Croplands and pastures	1.55 to 1.75 microns	Medium grey in this Band.
	2.08 to 2.35 microns	Light tone in this band.
Faults and fractures	1.55 to 1.75 microns	Shows linear topography.
Grasslands	1.55 to 1.75 microns	Light tone in both bands.
	2.08 to 2.35 microns	
Deciduous forests 1.	55 to 1.75 microns	Very dark in this band.
	2.08 to 2.35 microns	Light in this band.
Coniferous forest	1.55 to 1.75 microns	Very dark in this band.
	2.08 to 2.35 microns	Mottled medium grey in this band.
Defoliated forest	1.55 to 1.75 microns	Lighter in this band than next one.
	2.08 to 2.35 microns	Darker than pervious band.
Mixed forest	.76 to .9 microns 2.08 to 2.35 microns	Blotchy grey tones.
Moist Ground	2.08 to 2.35 microns	Irregular darker grey tones.

FEATURE	SPECTRAL REGION	COMMENTS
Nonforested coastal wetlands	2.08 to 2.35 microns	Clear demarcation between land and water
Silty water	.76 to .9 microns	Will delineate waters edge
	2.08 to 2.35 microns	Water will be dark in this band
Sand and beaches	.76 to .9 microns	Bright in all bands. Bands will
	1.55 to 1.75 microns	delineate water. Use also with quarries.
Underwater studies	.4 to .5 microns	Can see bottom in up to 150 ft of water
	.5 to .6 microns	Can see bottom in up to 90 ft of water
	.6 to .7 microns	Can see bottom in up to 30 feet of water
	.76 to .9 microns	Clearly marks water line

If you need to study these types of features, you will be forced to rely on LANDSAT, IRS, or ASTER data, because they are the only systems that give more information in the infrared regions. Most other systems focus on visible and near infrared light because that is the region of the electromagnetic spectrum that CCDs work best in. For more information on multispectral imagery and how it is manipulated, please read my book, *Satellite Surveillance*.

Computers and Software

In the early 1990s, the computer and software usually cost more than the satellite image. Imagery came on mainframe magnetic tapes, top of the line Silicon Graphics computers were required to process the imagery, and software ran into

several thousand dollars per copy. No wonder prints of satellite imagery were popular.

Today, you can still get a print of a satellite image, but most personal computers are more than capable of handling the large files and basic enhancement techniques. Consequently, if you have any serious interest in satellite imagery, use your home computer or shell out the few hundred dollars for a basic desktop computer. Take it from someone who has used both prints and computers — prints are a pain (and hard on the eyes).

There are several reasons for using a computer. First, the data from satellites is digital, so you are receiving information that is the closest to what the satellite actually sent. Second, many satellite image providers have web sites that can automatically send your digital image via e-mail once you pay online. No more waiting days or months for the image. Third, a computer screen is easier on the eyes when looking at imagery, especially since you can zoom in on an area of interest. Fourth, there are a lot of satellite imagery web sites that you can visit online (some like Space Imaging even offer free samples that you can play with on your computer to get practice). Finally, most basic digital photo software found on computers today can handle many satellite imagery enhancements (if you get into multispectral and hyperspectral imagery, a better suite of software will probably be required).

If all you have is a basic computer, you can handle most of the satellite imagery you will probably want to use. High resolution satellite systems like Ikonos, Quickbird, and SPOT all can send their images in popular electronic formats like tiff and jpeg. In many cases, these images are already manipulated so little if any electronic massaging is needed. Just load the image into your favorite image software, and you can trim it,

manipulate contrast, change tones, or whatever you want to do to make it a better product. In fact, current software is so good that 90 percent of my satellite imagery work is done with the free software I got with my computer. And, in most of those cases, it is just as good or better than the software that satellite specialists paid thousands of dollars for several years ago.

There are times, however, when cheap software can't do it. If you wish to merge several bands of imagery to create one color composite, or the satellite image format is designed for remote sensing, or you want to do more sophisticated analysis, you may have to shell out between $100 to $2,000. But, before doing that, check out some more sophisticated photo enhancement software found at the local computer or office supply store. Common photo software like Adobe can do wonders.

If these can't help, then the only solution is to buy some real satellite imagery software. Although there are many on the market, one of the best is ENVI (Environment for Visualizing Images). This state of the art image processing system is designed for satellite and airborne imagery and is used by scientists and the intelligence community. It can handle the latest multispectral and hyperspectral imagery and make it do handstands.

Computer software is also available that can take satellite imagery and make three-dimensional perspectives with it. We will cover that subject more in a later chapter.

So now you know the difference between spatial and spectral resolution. You know what parts of the electromagnetic spectrum are best for looking at different features. If you have a computer and have managed to download some satellite imagery to play with (if you haven't, try www.spaceimaging.com

and go to the gallery), I guess it's time to see what you can do with satellite imagery.

Chapter Four
What Satellite Imagery Can Do

So far, we have talked a lot about the theory of satellite imagery, but little on how you can use it in your own life, either to further an interest or to make money. With that in mind, let's look at how some others have successfully used it so you can have a better idea of its many applications.

Searchers of The Lost City (Archeology). It's the type of adventure that Indiana Jones would love; a fabulously rich city lost for nearly 2,000 years after mysteriously disappearing. It's a story interwoven with deadly vipers, mercenaries, and ancient curses. However, in this case, Indiana Jones would need to trade his whip and hat for a desktop computer and a digital satellite image; the tools several archeologists used to find the ancient trading city of Ubar on the Arabian Peninsula.

According to legend, Ubar was a rich, beautiful city built as an imitation of paradise. The Koran called it a place of, "lofty pillars," the like of which were not produced in all the world. It was also the source of many Arabian traditions like Aladdin and Ali Babba's cave.

Ubar's wealth wasn't due to anything magical, however. The town was the center of the frankincense trade. The bushes which produced the fragrant gum were grown about 50 miles to the south and caravans from all around the known world came to Ubar to purchase the expensive, crystallized gum. It's even possible that the frankincense given to the Baby Jesus by the Wise Men came from Ubar.

But all of its wealth didn't save it from a dramatic death around 300 A.D., when the Earth swallowed up the city, the sands covered it, and it disappeared. The Koran said it was a city of sinners that was destroyed by God, like Sodom and Gomorrah.

Every great discovery needs someone with the sole of an adventurer and Ubar had Nicholas Clapp, an Emmy winning filmmaker, who learned about the city when reading a book about a British explorer. He became interested in using satellite imagery, when he heard how Space Shuttle radar had discovered ancient riverbeds under the sands of Egypt. He wondered if something like that could find Ubar.

Clapp managed to convince NASA's Jet Propulsion Laboratory to help him and in 1984, the Shuttle's SIR-B flew over the Saudi desert in an unsuccessful attempt to find the city. They then tried LANDSAT imagery, but without success. However, rather than quitting like many would do, Clapp began looking at parts of the Arabian Peninsula that weren't considered likely locations for Ubar.

One of these scenes showed, in addition to the bright reflections of modern gravel roads, a faint network of ancient caravan trails coming together at Shisar. These trails were the paths taken by thousands of animals carrying their precious cargo to the remote parts of the known world like Rome, Jerusalem, and Greece. The reason they hadn't noticed it before

was that the site wasn't in the Empty Quarter as originally believed, but just to the north of it. Nor, was it ever covered by sand dunes as proclaimed by legend. When scientists went to Oman to brave desert mercenaries, scorpions, and vipers, they discovered a city that mirrored the descriptions of Ubar in the legends. It appeared that as the town grew, it used more water and finally the limestone reservoir collapsed under the weight of the city, plunging the city into the earth.

In the movie *Indiana Jones and The Last Crusade*, a scholarly Indiana Jones tells his archeology students that X never marks the spot and there aren't any treasure maps. However, with the aid of satellite imagery, archeologists have the closest thing to a treasure map. Of course, finding the fame and fortune and adventure is still up to them.

Controlling Forest Fires (Forestry Management). A forest fire firestorm is just as dangerous as a nuclear explosion. Temperatures soar over a thousand degrees and wind velocities exceed 200 miles per hour. Any unfortunate human or animal caught by it dies from asphyxia as the oxygen is sucked from its lungs.

Forest fires aren't just a threat to fire fighters and wildlife. Within minutes a firestorm can wipe out valuable lumber and vegetation that took centuries to grow. They can also destroy local economies dependent on tourist dollars.

For over the last decade, forestry officials have closely tracked fires with the help of satellite imagery. Thanks to the thermal and medium infrared bands on LANDSAT, they can see the fires, even when the scene is covered in smoke, while other types of satellite imagery help them access damage and future threats.

Satellite imagery can do more than just monitor a forest fire. With satellite imagery, an analyst can differentiate varieties of

vegetation and monitor their health, thanks to three characteristics of plants, chlorophyll, leaf structure, and water content. Obviously the last one, water content, is critical to determining the fire threat.

The more water a leaf contains, the less mid-infrared light is reflected into space. Obviously, this effect provides an ideal tool for measuring the impact of drought on a forest. Information like this is invaluable to forestry managers who want to know where vegetation is dry enough to fuel a fire.

The traditional tool for studying a forest is the color infrared image. This image highlights all the vegetation in a scene and gives the viewer an idea of the condition of the plants. Sick plants will either be a pale green or red (depending on the type of color infrared image), while healthy plants will be a bright color.

Sunken Spanish Galleons and Buried Pirate Treasure (Archeology). Satellite imagery has also been used to hunt for Spanish galleons in the Caribbean, off the coast of Belize. The coast is protected by barrier reefs upon which old ships often ran aground, before better navigation techniques were discovered. Since the visible (blue, green, and red) bands can be used to see underwater, scientists have used satellite imagery to see anomalies on the ocean bottom. The idea is that a sunken ship will be higher than the surrounding bottom and will reflect light differently. Although the anomalies might not be ships, it narrows down the area to be searched. So far this technique hasn't found anything rewarding, but it remains a valid technique for the treasurer hunter.

There are other potential treasure hunting methods that can use satellite imagery. Scientists also looked at the coast of Nova Scotia, where pirates often came to bury their treasure. The idea was to look for unusual features along the shoreline,

but nothing came of it. "There were too many unusual features," said one imagery analyst involved in the project. However, if this technique were combined with some good data from other sources, well, who knows!

There are others who want to use satellite imagery to find caves, where treasures may be hidden. Once again, nothing of value has been found using this technique, but imagery can be used to narrow down the search area by locating limestone formations, where caves are common.

Monitoring the Colorado River (Water Consumption). No matter how low the temperatures are in the East and Midwest, consumers know they can walk into a grocery store and find fresh fruits and vegetables. However, these out of season fruits and vegetables can only grow if they are watered by the Colorado River, and unrestrained demand would turn it into a muddy ditch if it were not constantly monitored. While the East and Midwest can be over-endowed with snow and ice during the winter, water is still a precious commodity in the Southwest.

Although pumping stations along the river measure the amount of water taken from the river, it is not a true picture of actual demand. Much of the water is used for agricultural purposes, and a large percentage of the water used for irrigation returns to the river via the ground water table. The only water that is actually consumed is that which evaporates through the leaves of plants, a process called evapotranspiration. Naturally, this percentage varies depending on the type of plant under irrigation, the temperature, and the hours of sunshine.

Determining agricultural water demand was once labor intensive. It required taking agricultural reports of what was being grown and determining water consumption by multiplying a crop's evapotranspiration rate by the number of acres.

Since the near infrared band shows plant health, it visibly shows if the field is being irrigated or the plants are in need of more water. Although there are differences in reflection depending on the type of plants and even if there is dust on the leaves, this drastically reduces the workload for the Department of the Interior.

Open Skies. (Reporting the news). The Iraqi war of 2003 was a landmark in the use of satellite imagery in reporting the news. Nearly every news organization had imagery of Iraqi targets, which was being updated on a regular basis. Viewers had an unprecedented view of what was happening behind Iraqi lines.

Despite this success, news organizations were slow to realize the uses of satellite imagery. The first application was in 1986, when the nuclear reactor at Chernobyl exploded. Given the secrecy of the Soviet government at the time, it was up to the LANDSAT and SPOT satellites to show and prove that there was actually an accident deep in the Ukraine. Information from LANDSAT 5 showed a bright area that was too strong to be a reflection of the sun. The only answer was an energy source with a temperature of about 1,000 degrees Celsius, meaning that the fire was still raging in the reactor's graphite core. Data from the satellite's thermal sensor showed that the cooling pond had a uniform temperature and wasn't being used for cooling, which meant that the reactors had been closed down for an emergency.

France's SPOT satellite soon confirmed the LANDSAT information and showed even more with its higher resolution panchromatic images. SPOT not only showed the damaged plant, but also even showed the scars of the blast. Thanks to the public revelations from the two satellites, the Soviet government was forced to be more open about the incident. And,

before you knew it, news agencies were scouring the world to find news stories that were once unobtainable to them.

The first story to use satellite imagery in investigative reporting was the ABC News report on the Soviet Krasnoyarsk radar facility. For years the U.S. government had accused the Soviets of violating the ABM treaty by building the Krasnoyarsk facility to track American ICBMs in their terminal phase. The Soviets vehemently denied it and claimed that the facility was for tracking its own spacecraft. The situation reached an impasse since many Reagan Administration critics felt the accusation was an attempt to push for more defense spending.

On April 2, 1987, ABC News used SPOT imagery to prove that the position and orientation of the radar made it impossible to track Soviet spacecraft launchings and the facility was, in fact, a violation of the ABM treaty. One result of this disclosure was that the Soviet government eventually agreed to dismantle the radar.

Since then, several news agencies have used satellite imagery in investigative reporting. CBN (Christian Broadcasting Network) News has been a pioneer in using satellite imagery in following the growth of weapons of mass destruction in the Middle East and North Korea. Often, their reports have elicited calls from congressional intelligence committees that have asked for more information because the investigative report provided more information than U.S. intelligence groups were willing to disclose.

As spatial resolution has improved, the amount of reporting on military issues has increased. Today's satellite imagery can clearly see and identify tanks, aircraft, and missiles. It can also peer into secret areas once closed to the public. And, with multispectral data, reporters can even detect camouflage and

heat sources from underground facilities. This is one part of the satellite industry that will grow in the future.

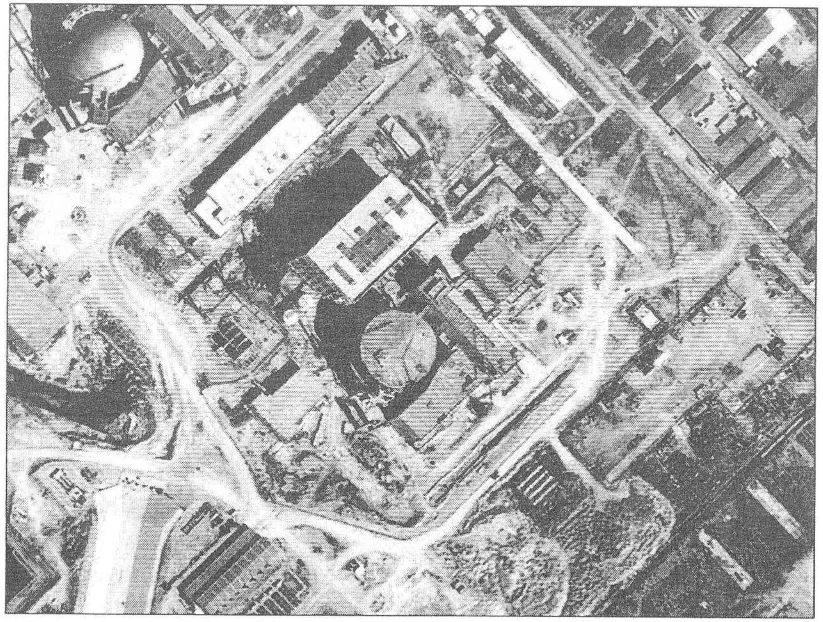

Figure 4.1

News groups that follow the proliferation of nuclear weapons have constantly monitored Iran's nuclear reactor at Bushehr. The reactor containment vessel in the center of the picture is still under construction. The one in the upper left hand corner is finished. (Space Imaging and CBN News)

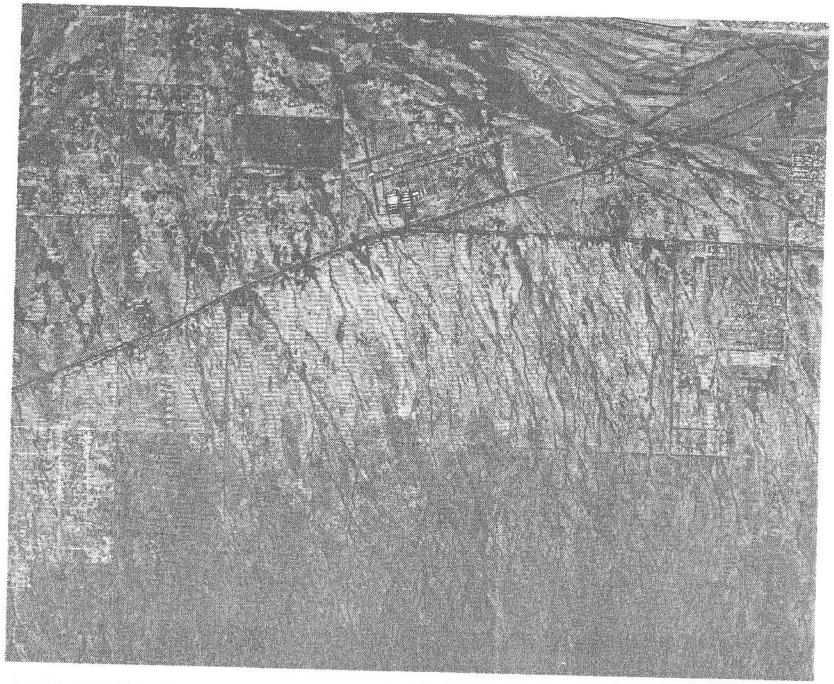

Figure 4.2

As areas like the west side of Tucson, Arizona, rapidly grow, satellite imagery is often the only way to keep track of development. I also use this type of imagery to find the best places to hunt for morning dove (dark areas where there is vegetation). (Space Imaging)

Down on the Farm (Agricultural Studies). It's part of the American farming tradition and as familiar as a Norman Rockwell print; a grizzled farmer steps outside his house, looks into the sky, and makes some quaint remark like, "we sure could use some more rain." Of course, American farmers are not the only ones who do this. For thousands of years, all farmers have looked to the sky for help, whether it be for rain

or sunshine. Today, however, farmers are looking to the sky for up-to-date satellite information.

Although satellite imagery has always held promise for farmers, it wasn't until recently that the imagery could be acquired and delivered fast enough that any potential problems could be rectified. For instance, a pest or plant disease that was starting on a field had to be detected and countered within a couple of days, or it would be too late to make a difference. That was hard to do in the past, when delivery times were longer and satellite costs were higher.

Today, a satellite can image an area, the data can be down linked to Earth, it can be processed, and it can be electronically transmitted to a farmer within the 48 hours of acquisition necessary to fix the problem. One of the common problems is plugged or improperly sized sprinklers in an irrigation system. Since the amount of water can dramatically affect a crop yield, the faster the information is available, the faster the sprinkler is fixed.

Selling the Public (Public Relations). Placating some environmentalists was actually easier than moving an eight foot square satellite image around Jacksonville, Florida. Consultants had to manhandle it around corridors, into elevators, and through rooms in order to make presentations. They even had to build a special carrier for the top of a car to carry it across town.

Difficult as it was to move this clumsy display around, the "grunts" charged with moving it agreed that the image of 730 square miles of northwest Duval County was indispensable to successful public meetings and presentations concerning Jacksonville's outer beltway. "It was a great presentation display," one manager noted. Without it, Jacksonville roads would have become as crowded as the elevator carrying the 8′ x 8′ image.

The Florida Department of Transportation was trying to sell an outer beltway for Jacksonville, but it was meeting with opposition from environmentalists afraid that the road would destroy wetlands, and by those who oppose growth of any sort. Although the original studies took the environment into consideration, the Department had to convince the opposition.

The large satellite image was a bother to move, but it was critical for the campaign. The image added credibility to the analysis at public meetings. By bringing the large photo, which showed wetlands, residential areas, and flood plains, the civil engineers took skeptical observers though the decision making process and showed what steps they took to limit environmental impact. As a result, opposition never coalesced as it has with other civil engineering projects.

One Florida engineer noted that most civil engineering presentations are poor and a satellite image helps the public relate better to the project. By showing environmentally sensitive areas, waste dumps, and residential areas, it reinforces why the decisions were made.

Witness for the Prosecution (Legal Evidence). How do you prove that a landowner has changed the ecosystem after a law was passed? That was the problem for the South Florida Water Management District, which is charged with monitoring over 100,000 acres of wetlands where farming takes place. The area is too large for traditional surveillance methods and much of it is far away from roads.

When the district finds evidence of environmental tampering, they have to prove that the work took place after wetland protection laws were passed. The answer was archival satellite imagery and newly acquired images. By electronically comparing the new and old imagery, helicopter pilots could be given locations of possible violations. If a change was de-

tected, the old satellite imagery can prove that the changes were made after the law was passed. Usually, when presented with this evidence, the land owner will chose to settle out of court and pay a fine.

Of course, what's sauce for the goose is sauce for the gander. Someone accused of damaging the environment can use old satellite imagery to prove that the damage occurred either before the law was passed or before the property was transferred.

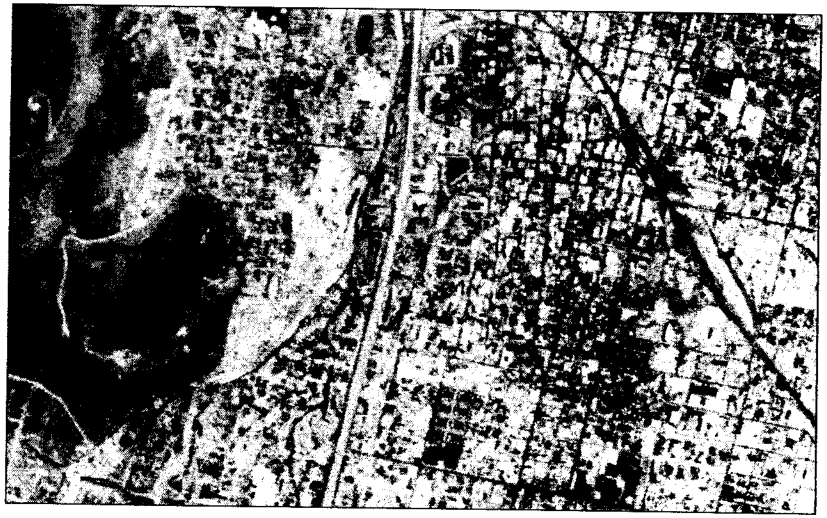

Figure 4.3
Downtown Tucson as it was in 1965. The historical barrio has been replaced by modern buildings for bureaucrats and lawyers.

Zoning, Land Use, and Permitting (Taxes and Law Enforcement). Unfortunately, Big Brother is here and he is watching you from space.

Since it's nearly impossible to send inspectors everywhere, more and more local governments are relying on satellite imagery to detect changes that would indicate construction or some other modification. Any changes can then be checked against tax and permit records, and inspectors can be dispatched as necessary. The result is more tax money for the government and more government control over your life.

Of course, satellites aren't perfect and it's possible that they can make a mistake. In a later chapter, we will cover how satellites detect changes in land use applications and their weaknesses.

The Way We Were (History). Satellite imagery is often a window into the past. In this case, it is the rapidly growing city of Tucson, Arizona. Figure 4.3 is the first known satellite image taken of Tucson, Arizona, by Mission 1021-1 in May 1965. The image shows the historical barrio that was torn down by city leaders in the name of urban renewal in the 1970s. With imagery like this and software that can make a satellite image a three-dimensional image, historians can recreate a scene that has been destroyed forever.

Chapter Five
A Thumbnail Guide to Interpreting

Needless to say, this is a subject that whole books have been written about, so there is no way that I can cover it with the detail that you may want. However, I'll try to cover the basics and then go into more detail on several areas that may interest you.

Basic Principles of Object Recognition

Thanks to modern air travel, most people are familiar with viewing objects from overhead and, therefore have little difficulty recognizing many features like roads, lakes, residential areas, etc. However, in order to become an accomplished satellite imagery interpreter, you need to engage your mind as you look at the imagery. Here are some of the factors that you should evaluate as you look at any satellite image.

Shape. This is probably the most critical, because shape alone will identify many objects like airports, roads, etc.

Size. Size is critical, especially if you are differentiating between a rural road and an interstate highway. In most digital satellite imagery, it's relatively easy to determine size and distance because the spatial resolution of the image is usually the size of one pixel of the image. Therefore, if the resolution is one meter and the object is four by three pixels in size, the object is about four by three meters.

Form Follows Function. Most objects are built in a certain way for a reason. In military reservations, wide curving roads are often built to allow the movement of long vehicles like missile transporters.

Tone and Color. If the image is a high-resolution panchromatic image, the different colors will register in different tones and shades. This can mean the difference between a tile and a slate roof or a cement or asphalt road.

If you have a color image, basic colors can tell a lot. For instance, a rectangle in a back yard in the suburbs that is blue, is probably a swimming pool. If the shade of the blue goes from light to dark blue, the light shade is the shallow side, while the dark is deep.

Time. Be aware of the day and time of day the image was taken. A parking lot that is full on a weekday may be a place of business, while one full on the weekend may be a shopping or recreational center.

Several years ago, a major international defense publication asked a photo interpreter to look at the Island of Abu Musa, which belongs to the United Arab Emirates, but was occupied by Iran several years ago. Since then the Iranians had fortified the island. However, the analyst reported that Iran wasn't involved in building any additional facilities, because he didn't

see any construction activity. If he had paid attention to the date the satellite image was acquired, he would have known that it was Friday, which is holy day for Muslims. A picture taken any other day of the week would have shown considerable activity.

Pattern. Patterns can indicate objects like parking lots. In agriculture, if trees are arranged in rows, it's obvious that they are a cultivated orchard rather than wild vegetation. If a field is plowed in a curve, rather than a straight line, it probably indicates a slope.

Site. The location of an object is helpful in identifying an object. A silo would be a logical identification of a tall cylindrical object sitting next to a barn. It might be a bit harder to identify if it is sitting in a mall parking lot (it might be an inflatable Budweiser beer can).

Shadow. This is critical for measuring heights and for recognizing tall objects like smokestacks and antennae. Unfortunately, they can also hide detail next to buildings. However, if you refer to the book *Satellite Surveillance*, you can see how a computer can reveal details hidden in the shadow.

Drainage. Looking at drainage, creeks, and rivers can give you an idea of relative elevation, soil conditions, and even vegetation. A wandering river or stream means that the terrain is flat.

Texture. The amount of coarseness on the object can indicate what it is. For instance, it is often hard to tell if a military vehicle is wheeled like an armored car, or tracked like a tank from space. However, by looking at the ground around the vehicle, you should see the scarring caused by treads, especially in turns.

As you start interpreting the image, begin to look for interrelationships. If the image is of a rural farming community, you

should see barns, silos, pastures, livestock and crops. There may likely be some signs of food distribution (depots, trucks, warehouses, train system, etc.). From these observations, you can make some general assumptions about the area and people.

Since it can be easy to focus on one factor, photo interpreters often use checklists to remind them about what they should be focusing on. Although we will be going into more detail in later sections, here's a checklist of basic features that you will want to make a note of in a basic interpretation.

Natural Features

Forests
Tree farms
Natural vegetation
Pastureland
Crops and fallow fields
Irrigated crops
Orchards
Parks
Shorelines and beaches
Livestock
Bays and inlets
Swamps or marshes
Floodplains
Rivers and streams
Lakes and ponds
Sand bars and mud flats
Limestone and sinkholes
Cliffs
Erosion features
Rock outcrops
Water drainage
Faults
Talus slopes and alluvial fans
Hogbacks

Manmade Features

Apartment buildings
Mobile homes
Private homes
Schools
Stores, shopping centers, and malls
Government buildings
Churches
Parking lots
Sports fields
Secured facilities (prisons or military compounds)
Open pit mining
Quarries and sand pits
Underground mining
Oil and natural gas wells
Electrical power plants
Electrical power distribution systems
Buried pipelines
Petroleum and Chemical industries
Manufacturing

Natural Features

Anticlines

Manmade Features

Roads (dirt, two lane, four lane, etc.)
Railroad lines, yards, and terminals
Truck terminals and warehouses
Airports
Radio or TV towers
Dams
Bridges
Ports and ferry landings

Developing an Expertise

One of the nice things about interpreting satellite imagery is that it is so democratic. Everyone has a specialty that sets him or her apart from the rest. For instance, a truck driver could look at an image of a truck depot and warehouse and tell us more about the operation than a professor in photo interpretation. Landscapers, longshoremen, farmers, military people, and any other occupation have a unique perspective that they can bring to satellite photo interpretation. Therefore, it pays to specialize in what you know. Conversely, if you have lived your whole life in New York City and want to study agricultural imagery, in order to make a killing on potato futures, you are probably going to blow it.

Of course, you probably won't know enough to be an instant expert, but if you go with your profession or interests, you have a head start. The next step is to expand your knowledge based on your area of expertise. For instance, if you are a landscaper or enjoy gardening, you probably have a better understanding of vegetation and its requirements. Build on that by studying more about forestry and agriculture. As you go

along, you will find areas that you understand better. Continue to focus on those areas.

As you improve, you will want to buy more books that will help you in satellite interpretation. These are often available at used bookstores near universities that offer aerial and satellite interpretation courses. Don't be put off if you find an old book about aerial interpretation. Given the current spatial resolution of satellite images, they are very similar to aerial photographs.

There are other types of books that can help as you develop your specialty. College textbooks on industrial processes and engineering can help you identify certain industrial sites. A college chemical engineering book can help identify chemical processes, even if you can't understand all the writing. And military history books can often give insight into what is happening on a military base.

Of course, I can hear you asking, "How can I, an amateur, hope to compete with professionals?" Actually, it is easy. Right now, there is more satellite imagery than there are satellite analysts. That means that there are a lot of things left undiscovered and underutilized in satellite imagery. Although you may not be as good, if you spend more time on one satellite image, you will see things the professionals missed because they were looking at it too quickly. Besides, you may have other advantages like a greater familiarity with the area, the chance to go back to the image often, and a personal passion that the professional doesn't always have.

So much for the basics. Let's look at some specific areas of satellite interpretation that can benefit you.

Archaeology

Aerial imagery has been used in archaeology since the 1920s. Its first application was accidental and occurred when some Royal Air Force photographs were shown to Dr. Crawfors, who founded the magazine *Antiquity*. These photos clearly showed the pattern of a Celtic field system from overhead. Since then, it has been a critical part of uncovering lost sites and, as a result, in World War II many archeologists in Britain were employed in military photo interpretation. Today, as we noted earlier in the discovery of the ancient city of Ubar, satellite imagery is beginning to fill the same role.

There is probably no better example of using satellite imagery in the United States to find an undiscovered archaeological site than Chaco Canyon, New Mexico. Although they could not be seen from the ground or even the air, infrared sensors detected prehistoric Indian roads in the canyon that date from 900 or 1,000 A.D. These roads, which were 20 feet wide, were seen as straight lines on the satellite image. In later research, the scientists discovered over 200 miles of roads that apparently connected the people·of the area to sacred places and Chaco Canyon.

One of the most important indicators of archaeological sites are "plant marks" — visible differences between vegetation on a site and that in the surrounding area. For instance, in an area where there is an ancient ditch that has since been covered up by dirt and humus, vegetation will often be more lush because water seeps into the ditch and accumulates there, especially during dry times of the year. Conversely, a stone wall, road, or foundation that has been covered up will inhibit root growth

and interfere with moisture travel, which will stunt plant growth.

Figure 5.1
This imagery of Chaco Canyon, New Mexico, shows several straight Indian roads (right hand side of the image) that were built over a thousand years ago. (NASA)

Grasses seem to be the best indicator of uncovered walls or ditches since the plants are sensitive to variations of the soil and grow closely together. In the Great Plains, it's not uncommon to find circles that indicate where Indian lodges were built centuries ago. Of course, some of those circles are noth-

ing more than buffalo wallows, so ground research is necessary.

The best time to look for plant marks is during the growing season and the best satellite imagery to use will include the near infrared band, which highlights plant health. If possible, the image should be acquired after a short dry spell because the vegetation will be more stressed and any differences in plant health will be more pronounced.

The same principle can also be used in dry areas like the Southwest, where it may take centuries for vegetation to recover from damage. In arid parts of the Southwest, once the vegetation has been destroyed it's very hard for the soil to recover. The bacteria and nutrients common in wetter climates are missing, which makes it harder for vegetation to take root again. In time, rainfall erodes the little useful soil, which makes recovery that much harder.

Thanks to the fragile Southwestern environment, it's relatively easy to discover signs of the Western movement. Some of the objects that can be seen are trails, mining camps (often very visible thanks to the mine tailings and excavation), forgotten ghost towns, and abandoned homesteads. Unlike the grasslands of the Great Plains, infrared imagery doesn't have the strong infrared reflection from the sparse vegetation. However, barren land usually is quite bright, so the high resolution panchromatic imagery is often good.

This brings us to the next indicator of archaeological sites, soil marks. In the Eastern United States, Indians who lived near the ocean would often eat clams and mollusks. Consequently, scattered seashells often mark their sites. In areas where there is less vegetation, Indian sites can be detected by looking at pebbly areas, where rocks have been cleared.

Trails are often also found by soil marks. Whether it is the hooves of animals or wagon wheels, in the Southwest, the dry soil would be broken up and blown away as dust, leaving brighter rocks exposed.

Old mining sites are a natural for soil marks. Tailings piles of waste rock or processed ore will likely be a different color or tone (in a panchromatic scene) than the surrounding soil.

In any of these cases, a high resolution panchromatic image is one of the best tools for soil markings. If you want to use multispectral imagery, the mid infrared bands (1.55 to 2.35 microns) will show different soils and their moisture levels quite well.

Shadow marks are also a useful tool for archaeologists, although most satellites are programmed to fly over a site in the mid morning, when shadows are less. The theory is that walls and other high points underground will throw a shadow. This works best in the early mornings and late afternoons, but satellite images taken in the mid morning may still help in discovering an archaeological site. Again, high resolution panchromatic images are the best for this type of research.

Another technique for finding archaeological sites is to look for habitability marks. For Indians, habitability marks might include access to fresh water and lush vegetation, where animals might be found (hunter Indians) or berries and fruits are common (gatherers). In this case, mid infrared imagery will highlight healthy vegetation. In areas of the world where water might be scarce, satellite imagery might be used to find signs of ancient catchment pools where water would be stored.

Military Interpretation

Although satellite imagery is more and more a civilian industry, military affairs still cast a large shadow over the business. In this case, there are two aspects: military use of civilian imagery and civilian monitoring of military issues.

Although the military and intelligence communities have a fleet of spy satellites, they still use commercial satellites for intelligence purposes, as evidenced by the inability of commercial clients to acquire satellite imagery over the Middle East during the Iraqi Campaign of 2003. The fact is that the U.S. intelligence community has tens of thousands of targets that it wants to monitor and it's hard to monitor all of them with its own constellation of satellites.

Although commercial resolution isn't as good as that of the spy satellites, there are still many missions that they can handle. Coarser spatial resolution imagery like that from LANDSAT can be used for crop harvest estimates, maps, cross-country mobility, and construction. Higher spatial resolution imagery like Ikonos and Quickbird can be used to identify and count equipment, develop targeting data, and monitor lower priority installations. It can also be plugged into training devices so pilots can practice bombing missions.

Satellite imagery can also be used by the military in many cases where spy satellite data is too sensitive to use. Reconnaissance patrols can use it to have a current source of data for the area they will patrol. Snipers can use imagery to plan infiltration routes, calculate fields of fire and determine distances before a mission. Patrols can use imagery to see if a trail has been recently mined by looking for the scarring that indicates disturbed soil. Ambushes can be planned in advance. Mission information can be given to everyone involved without worry-

ing about compromising intelligence sources. The applications are limitless.

One of the most popular uses of commercial satellite imagery is following military developments that were once hidden from the general population. Over the past ten years, satellite imagery has been used more often to show television viewers foreign military installations that pose a threat to world security, especially those that either produce or store weapons of mass destruction. In that regard, they have made for a more informed electorate, but at the same time, have been used by some groups to push their own agenda.

One example of agenda driven satellite imagery interpretation was North Korea's missile test site at Taepo Dong. One Washington-based think tank that monitored WMD development, but opposed the development of an American anti-ballistic missile program, released imagery of Taepo Dong and claimed that its interpretation showed the site was too simple and crude to allow for development of a North Korean missile that could reach the United States. Therefore, they reasoned, there was no reason for developing an ABM system.

However, other analysts looked at the imagery and saw enough of an infrastructure to warrant concern by America. Inevitably, that concern was borne out, as it was later revealed that these nuclear missiles could reach the U.S. All the imagery proved was that a simple site could be used to develop long range ballistic missiles. You don't need a Cape Canaveral to produce and test ICBMs.

The growth of this civilian defense monitoring industry has created a need for more information on what to look for. With that in mind, here are many of the military objects that can be found at military installations.

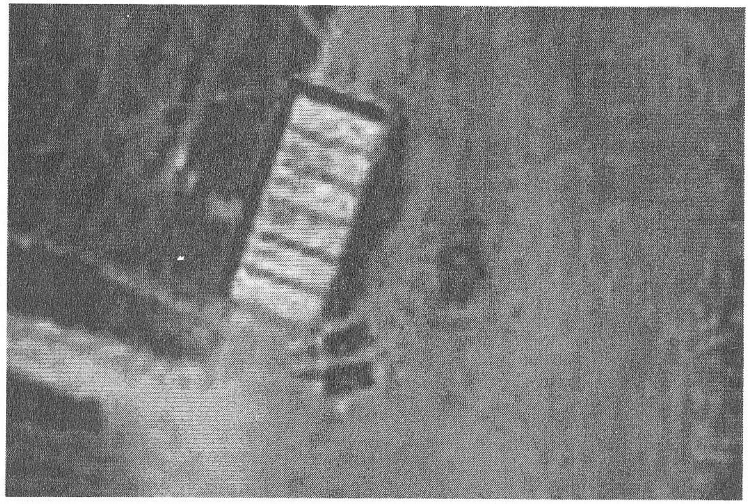

Figure 5.2
Thanks to higher resolution satellite imagery like this one meter Ikonos image; one can see the barrels that identify these vehicles as Syrian tanks. (Space Imaging)

Figure 5.3
These are Syrian howitzers positioned in revetments. (Space Imaging)

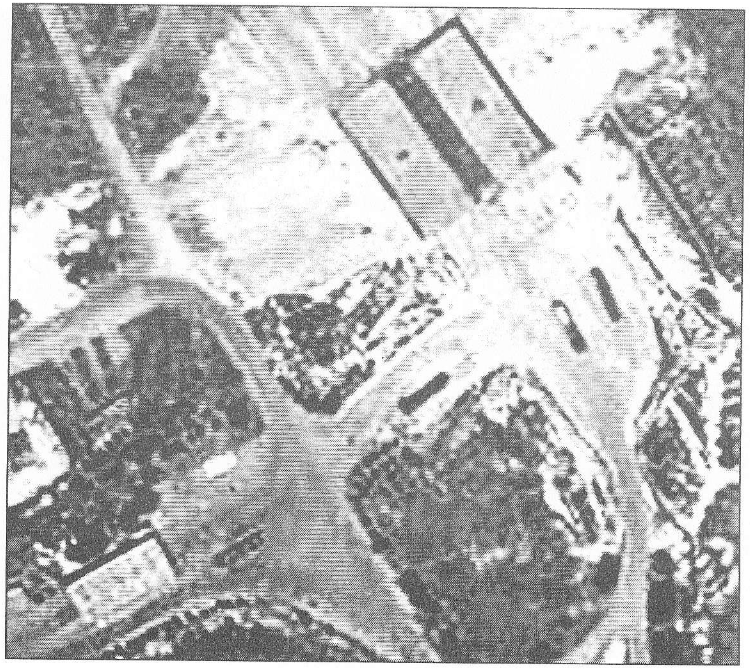

Figure 5.4
Several Syrian Scud transporters are seen outside buildings at this facility near Homs, Syria. The building in the lower left hand corner is a drive-through building that is used to accomplish maintenance on missiles or to load warheads. This is a critical feature at missile sites. (Space Imaging)

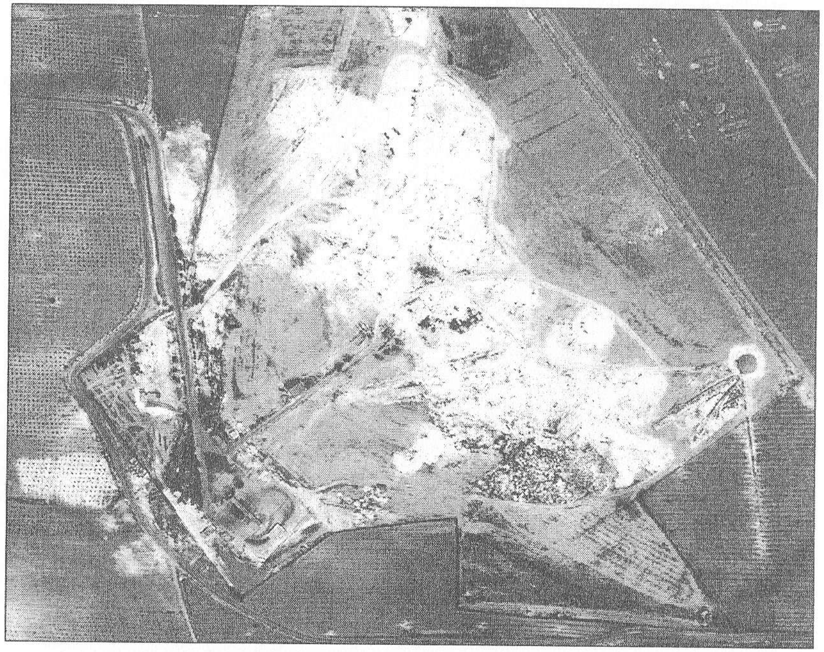

Figure 5.5

This suspected chemical weapons facility near Homs, Syria has several interesting features. It has a clear fence perimeter surrounding the facility, which indicates its sensitivity. It has a gentle curving road coming in from the upper left side of the image, which indicates it is probably used by missile transporters, which can't make sharp turns. It has a drive through building in the lower left hand side, where missile warheads can be mated to the missile. There are also several cement igloos inside the perimeter (one is clearly visible on the right side of the image). (Space Imaging)

Figure 5.6

Look for the unusual. Large jet aircraft aren't unusual at airports, but they are rarely found on an island without an airport. This passenger aircraft is at the terrorists training facility at Salman Pak in Iraq. Terrorists could sharpen their hijacking skills here before taking a civilian aircraft with hostages. (Space Imaging)

Figure 5.7
A ballistic missile site in Saudi Arabia. On the left hand side of the image are several bunkers, where the missiles are stored. On the right hand side is a missile maintenance site. Note the drive-through buildings for the missiles and their transporters. (Space Imaging and CBN News)

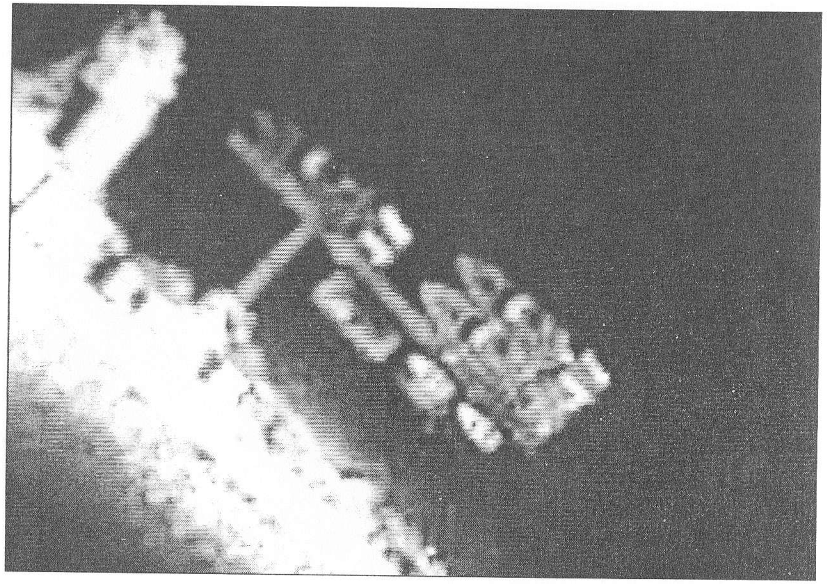

Fig 5.8
Three Chinese-made Hudong missile boats docked next to the Iranian nuclear reactors at Bushehr. With one-meter resolution, and reference books like Jane's Fighting Ships, one can identify most military naval vessels. (Space Imaging and CBN News)

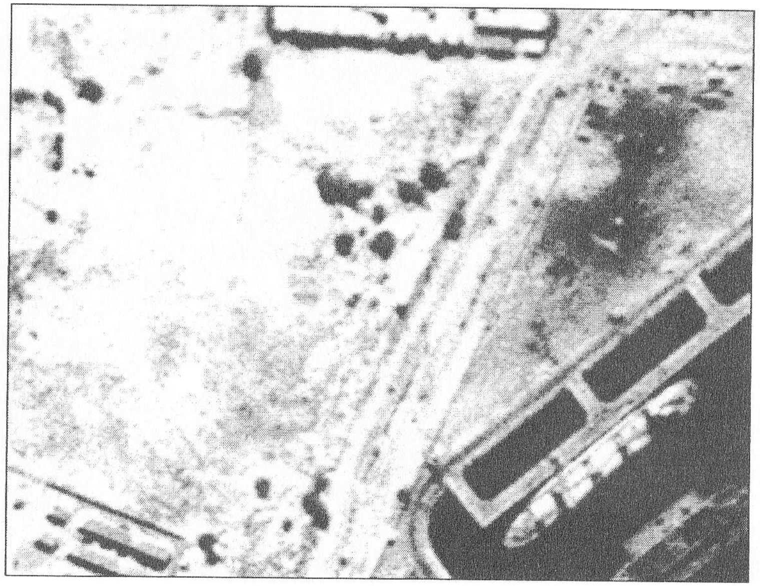

Figure 5.9

Merchant ships can be identified with Jane's Merchant Ships. The ship seen in this Russian KVR-1000 satellite image is a Chinese ship delivering missiles to the Iranians in Bandar Abbas. The missile containers can be seen on the deck of the ship. (Sovinformsputnik)

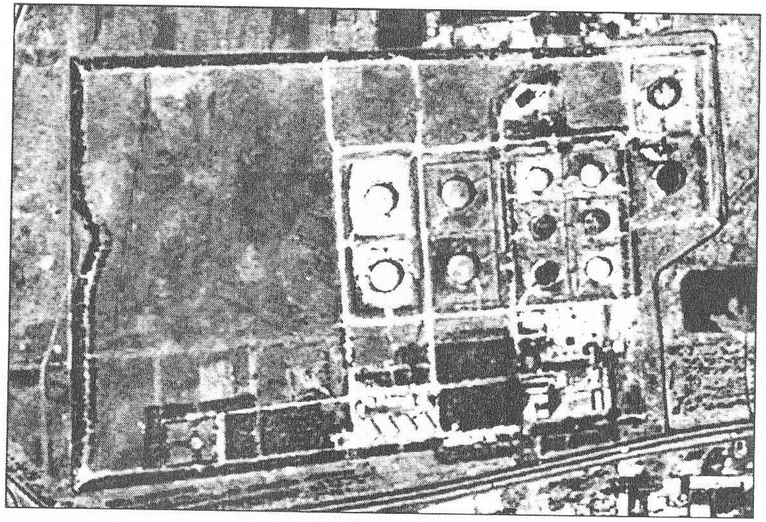

Figure 5.10

Sites involved in chemical weapons production are often found near refineries. This suspected chemical weapons precursor production site is near Homs, Syria. Unlike the nearby refinery, this site is surrounded by two fences and guard towers (always check places with security perimeters). (Sovinformsputnik)

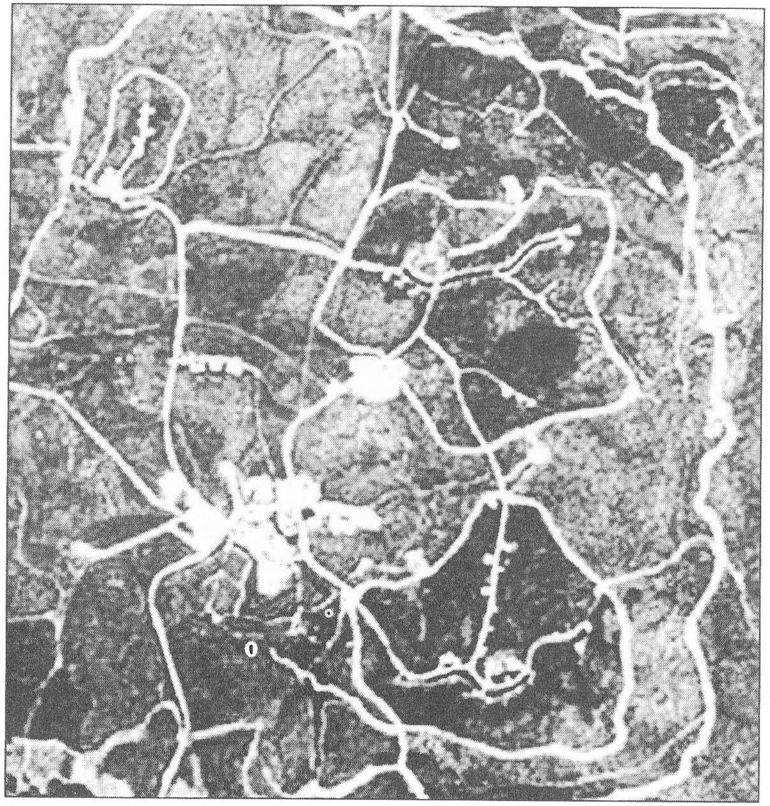

Figure 5.11
Even lower resolution satellite imagery has uses. This Russian image of Israel's nuclear missile site at Zackaraya has a spatial resolution of 5 meters, but still clearly shows the perimeter and roads leading into bunkers in the side of hills. (Sovinformsputnik)

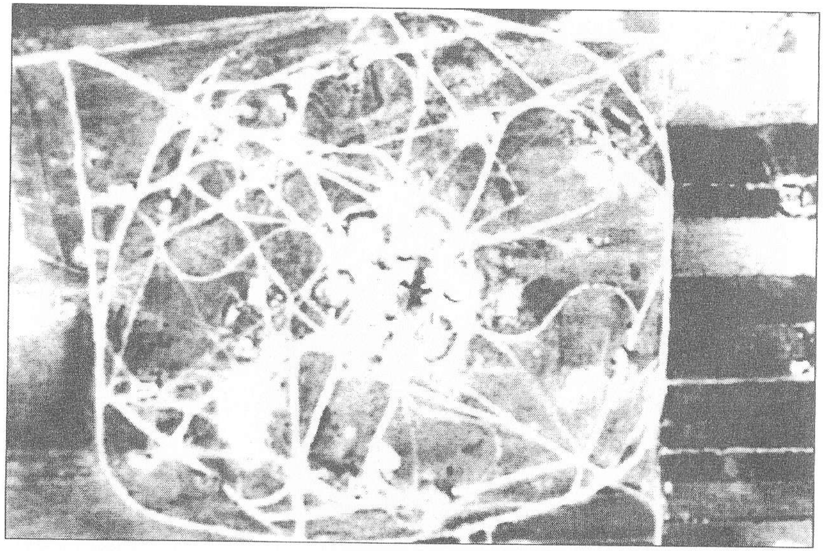

Figure 5.12
This is a classic Russian surface-to-air missile site taken by a Russian KVR-1000 satellite. The radar is in the center, while the missiles are on roads on the outer perimeter. (Sovinformsputnik)

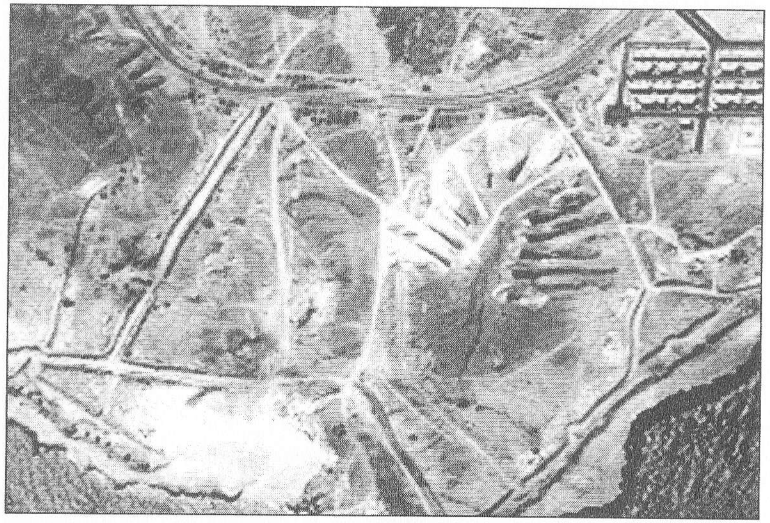

Figure 5.13

Silkworm anti-ship missile bunkers on the island of Abu Musa. Missile bunkers are often dug into the side of hills, where they can be kept until moved to their launch pad in the lower left hand corner of the image. Military barracks are visible in the upper right hand corner. This island, owned by the United Arab Emirates, but illegally occupied by the Iranians, sits astride the world's oil shipping lanes. These missiles pose a threat to every tanker that goes into the Arabian Gulf. (Space Imaging)

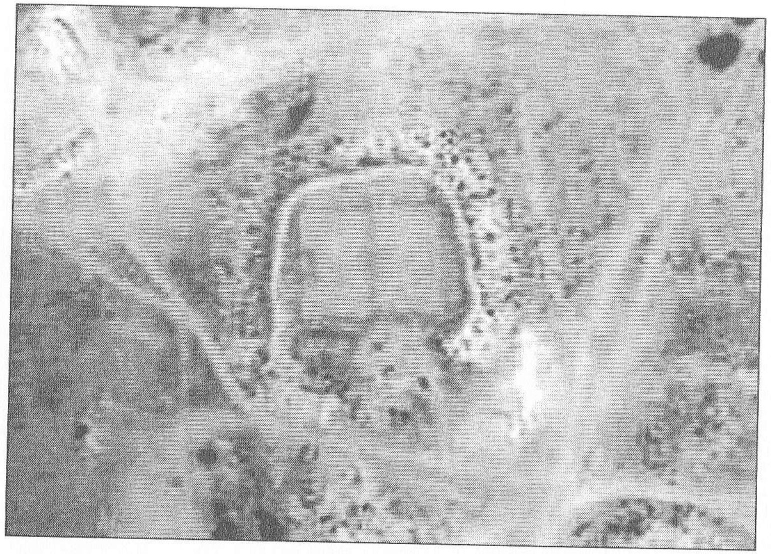

Figure 5.14

The open area inside the revetment is probably a pre-surveyed launch site for an Iranian surface-to-surface ballistic missile. In order to limit the time the missile transporters are out in the open and vulnerable, engineers clear and survey the site. The missile operators already have the targeting information, so they merely have to raise the missile and launch it. As you can see from the faint markings, the site has been camouflaged as a soccer field. (Space Imaging)

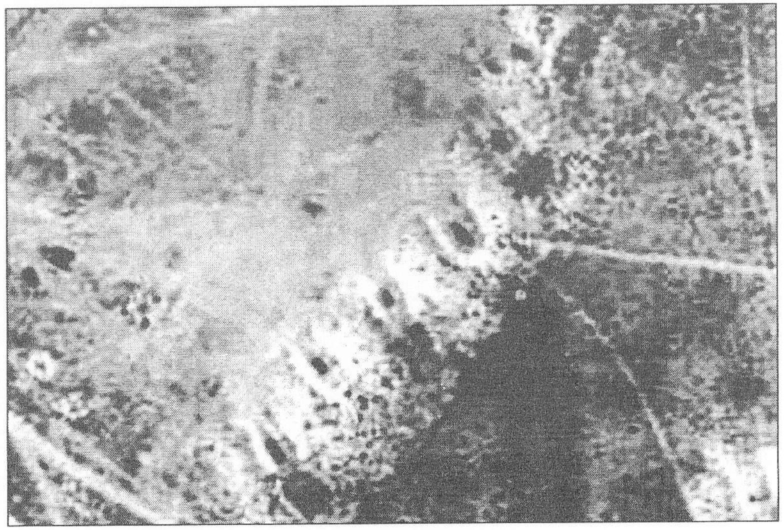

Figure 5.15

Silkworm missiles on the southern side of Abu Musa. While many analysts may think they are tanks, it is obvious that one meter resolution imagery can show the gun barrel (see the earlier image of Syrian tanks), which these lack. Note that the area behind the vehicles isn't scarred from the tracks, so they are wheeled. (Space Imaging)

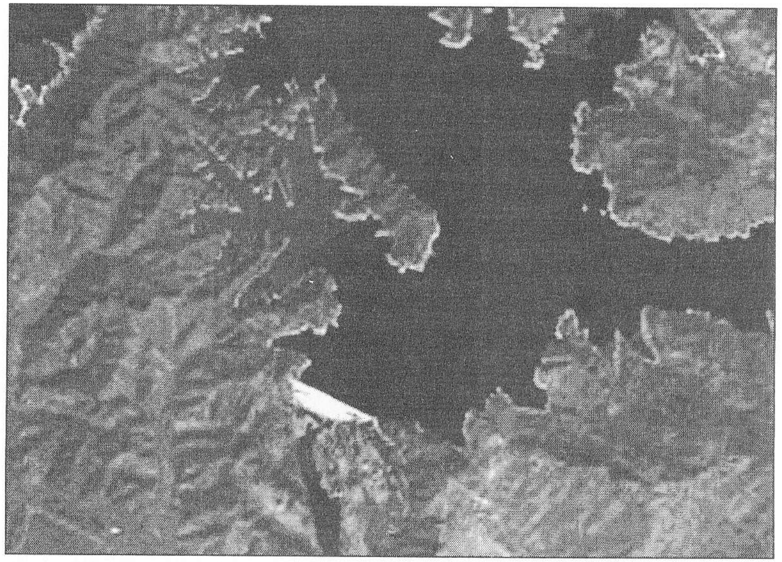

Figure 5.16

Dams and the electricity that they produce are often critical to weapons of mass destruction production. This North Korean dam (lower center) is critical to nuclear weapons development. The satellite image is a Russian KFA-1000 with five-meter spatial resolution. (Sovinformsputnik)

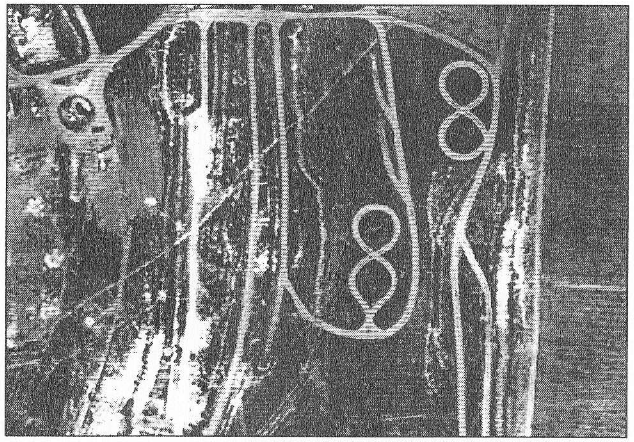

Figure 5.17
Training sites for missile transporter drivers have driving courses where they can practice sharp turns. Note the figure eights, which are a regular feature. (Space Imaging)

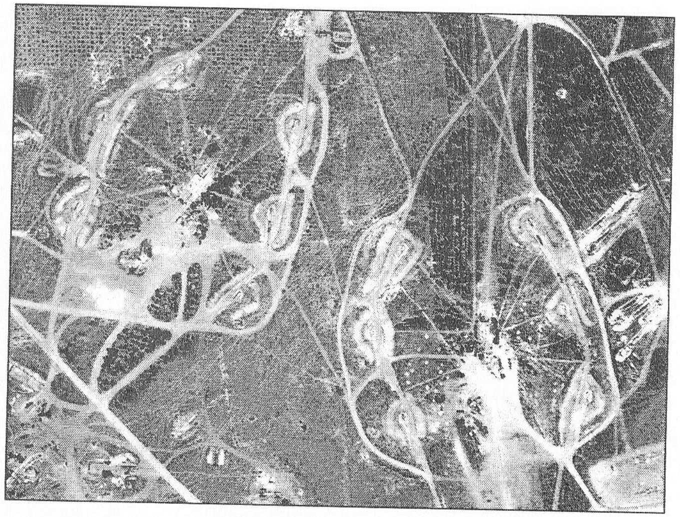

Figure 5.18
Syrian missile launch pads. This site near Homs, Syria is used by Syria to test its Scud missiles. Revetments surround these two launch pads where vehicles and testing equipment can be parked during a launch. (Space Imaging)

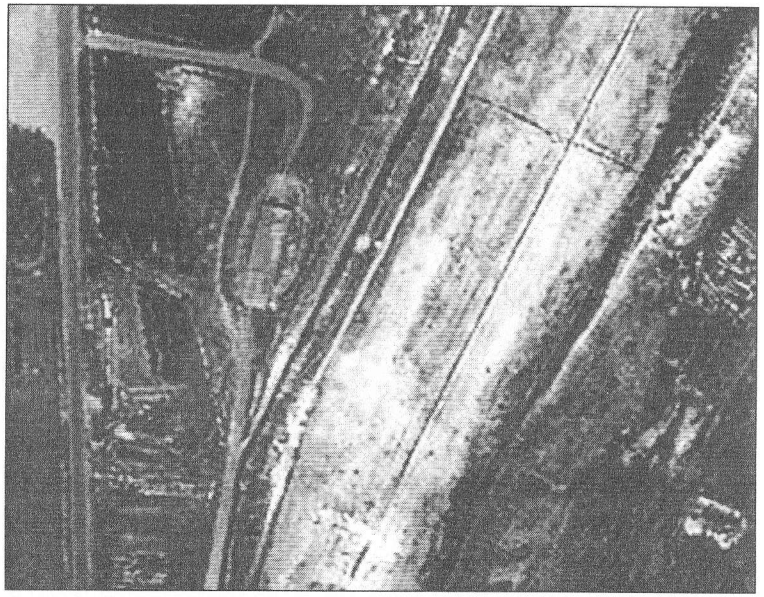

Figure 5.19
Another drive-through building (left center) and a gentle curving road (left upper corner). The empty decontamination pool next to the building (right side) means the building is probably used for loading toxic fuels onto Syrian missiles. The rows on the left side are trees that obscure the building from the road. (Space Imaging)

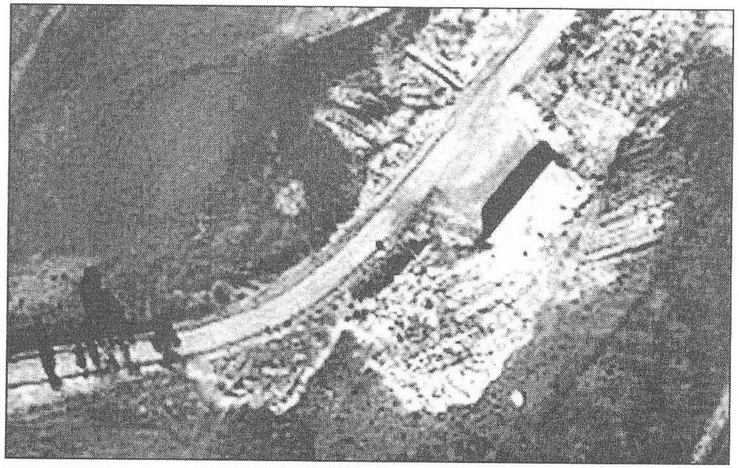

Figure 5.20
Missile bunkers are often dug into the side of hills. This Syrian Scud missile bunker near Hama, Syria is built in a narrow valley so Israeli aircraft will find it hard to bomb. (Space Imaging and CBN News)

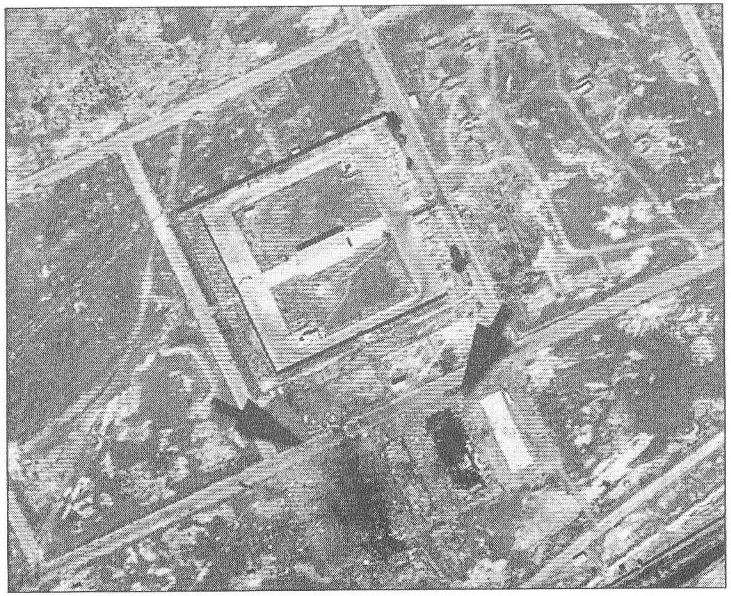

Figure 5.21

Scarring from bomb damage is easy to see. The arrows point to two buildings destroyed by U.S. air attacks in Basra, Iraq in 2003. Just above them, you see another drive through building indicative of a missile facility. (Space Imaging)

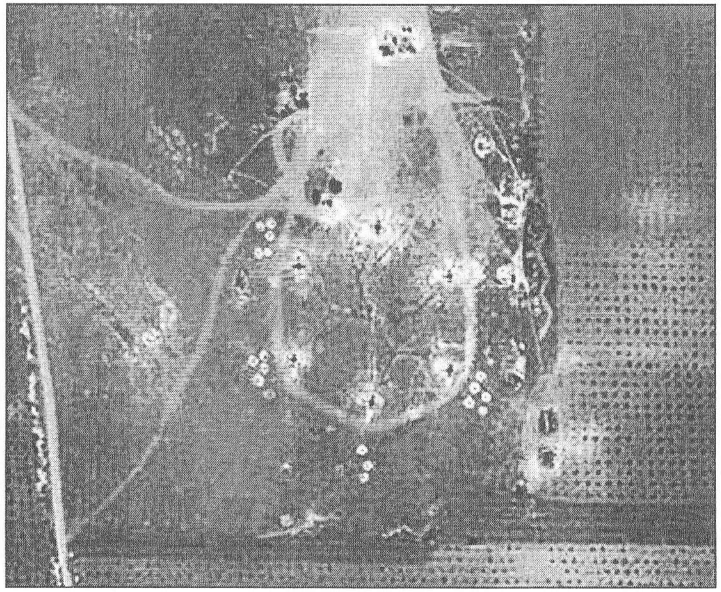

Figure 5.22

An anti-aircraft artillery (AAA) position. Like a surface-to-air missile site, it is circular, but the artillery pieces are smaller than missiles and look more like howitzers. (Space Imaging)

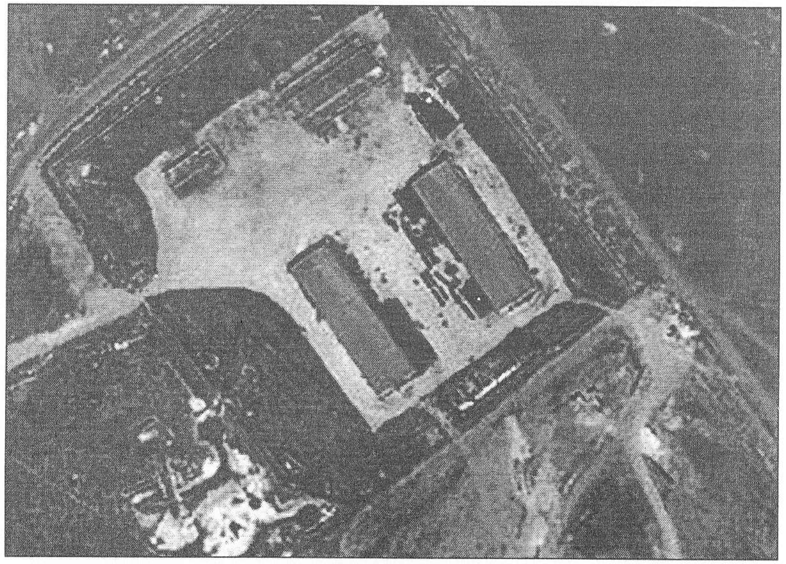

Figure 5.23
Although tanks, missiles, and other weapons can be hidden, the infrastructure that supports them is harder to hide. This warehouse at a Syrian Armored division is holding hundreds of drums. It is quite possibly a fuel and lubricant depot. (Space Imaging)

Figure 5.24
Many critical military installations are hidden from satellite interpreters. This image of the Taji Missile Component Fabrication Site looks like a normal industrial facility. In that case, additional intelligence is required. (DoD)

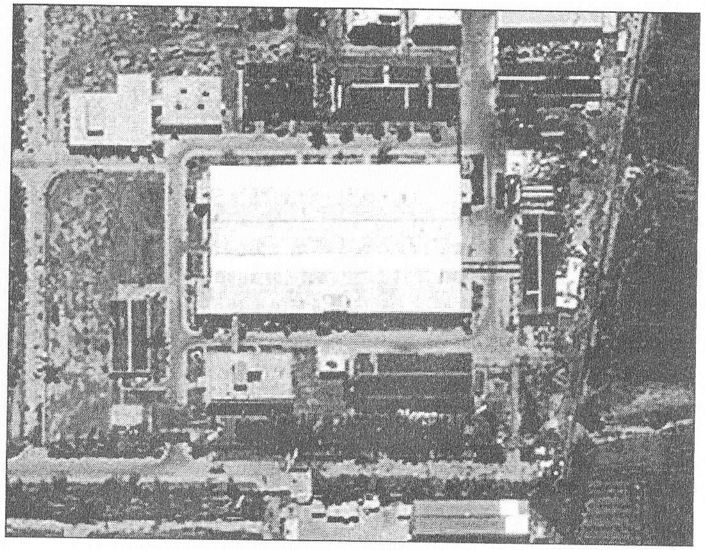

Figure 5.25
Comparing imagery over a period of time is critical to interpretation. In this image, you can see that the building damaged in figure 5.24 has now been repaired. (Space Imaging)

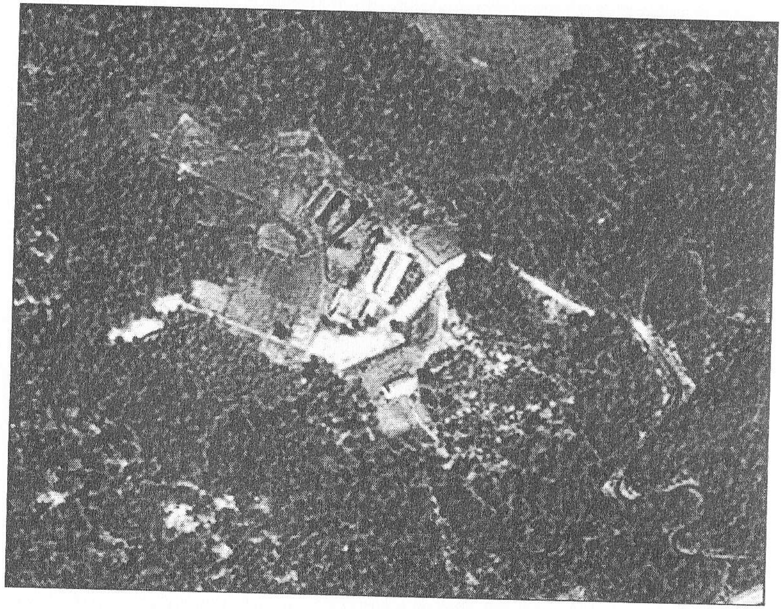

Figure 5.26
Ask questions of yourself. Although the North Koreans had promised to stop nuclear weapons development, this facility in Yong Byon, North Korea was built within walking distance of the closed plutonium separation facility. This facility was hidden in the woods so it wasn't visible to international inspectors. It is possibly a facility to extract plutonium from wastewater. (Space Imaging and CBN News)

Figure 5.27
Always keep an eye open for underground facilities that have a security perimeter. This Russian KVR-1000 image of Bandar Abbas, Iran shows the Iranian Air Defense Command. The clues are a road leading underground and a security perimeter. (Sovinformsputnik)

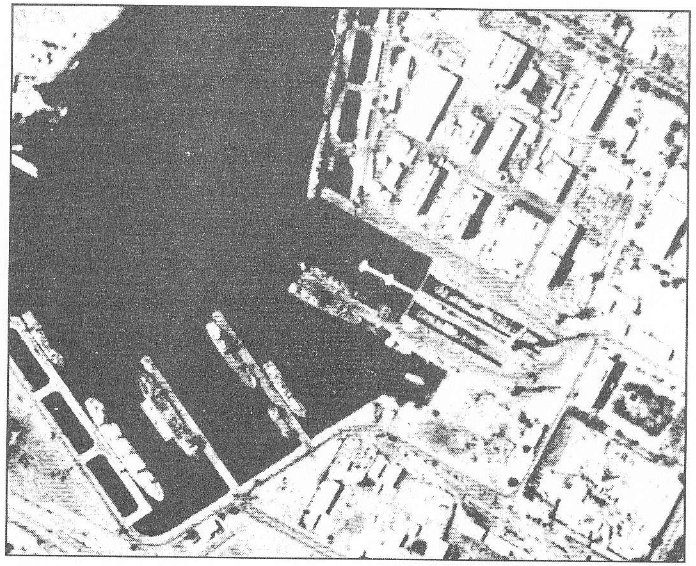

Figure 5.28
The Iranian naval facility at Bandar Abbas. While merchant ships have wider beams in order to hold more cargo, military ships are narrower and built for speed. Can you tell which are merchantmen and which are warships? Can you see the dry docks? (Sovinform-sputnik)

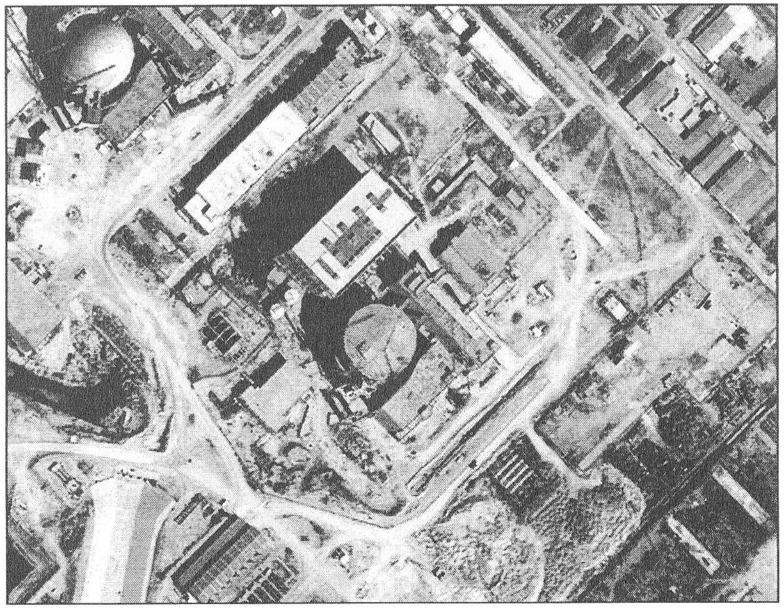

Figure 5.29
Two nuclear reactors at Bushehr, Iran. Nuclear reactors are easy to identify because of the large containment vessels (center and upper left hand corner). The reactor in the center is under construction. (Space Imaging and CBN News)

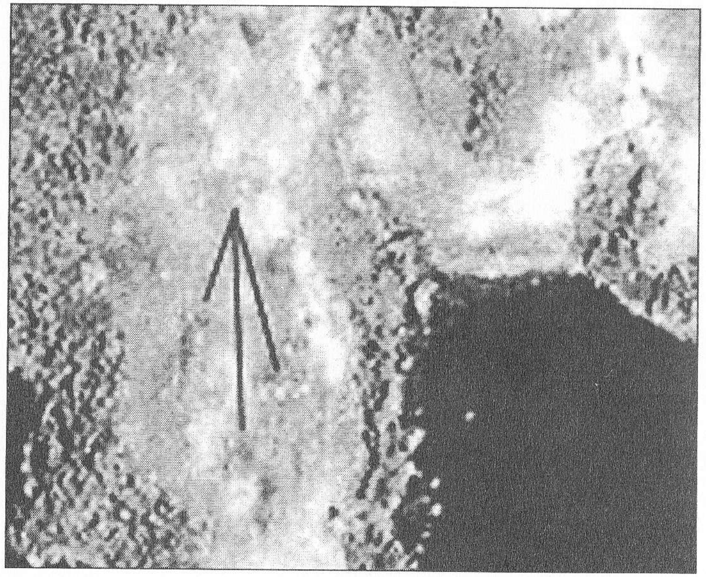

Figure 5.30
Camouflage makes interpretation difficult and often requires patience. Three camouflaged buildings related to North Korea's nuclear weapons program are barely visible in this image. Shadows and paths that lead to camouflaged structures are sometimes the best clues. (Space Imaging and CBN News)

Figure 5.31

Commercial satellite imagery is excellent for military planning. This image of a ballistic missile maintenance facility can be used to determine infiltration routes, sniper positions, enemy strongpoints, and distances. Ask yourself how you would carry out a raid on this site. (Space Imaging and CBN News)

Industrial, Commercial and Residential Areas

Although city planners have used satellite imagery for over a decade, commercial applications have been lacking. There, however, are many applications like marketing studies, real estate, and commercial development.

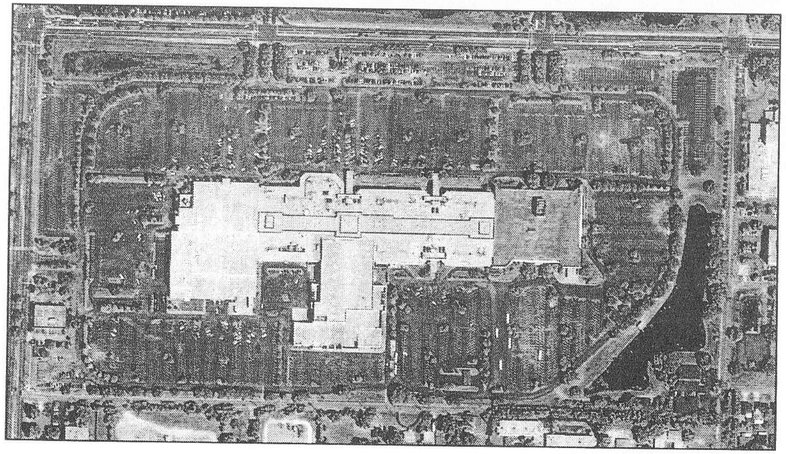

Figure 5.32

The typical American mall. A look at the parking patterns shows which stores are doing well and which are suffering. Since malls often precipitate more commercial development in the area, a potential real estate investor could use satellite imagery to analyze where future stores may go and what property might be a good investment. (Space Imaging)

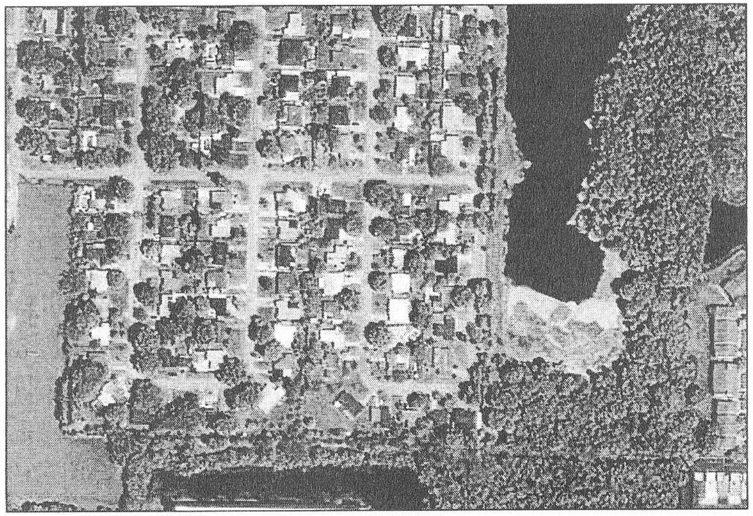

Figure 5.33

Satellite imagery of a residential area can give the viewer a good idea of the type of residents and their income. These views are also good for selling a property because they show amenities like this lake. (Space Imaging)

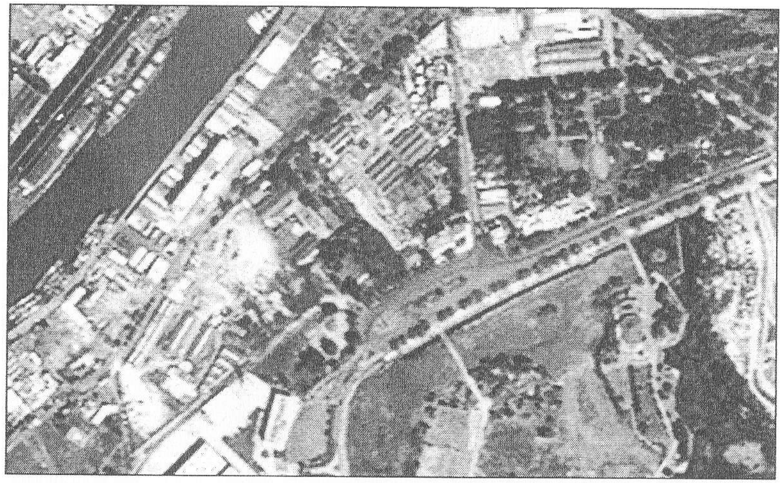

Figure 5.34

Commercial port in Buenos Aries has warehouses, as do most older ports. (Space Imaging)

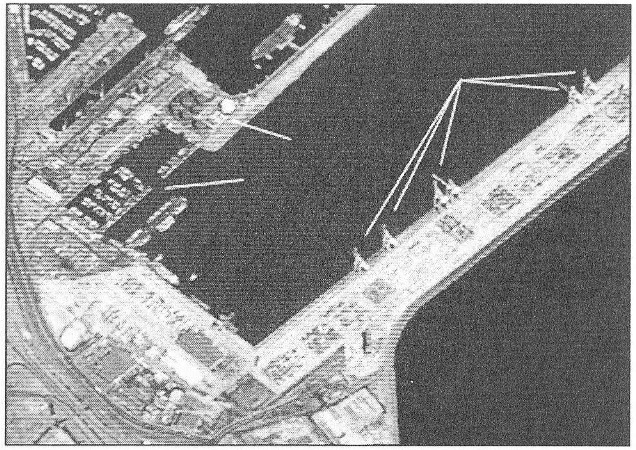

Figure 5.35
Modern ports like Cape Town's have fewer warehouses since the goal is to move goods quickly out of the port to the final destination. Here five cranes can move containerized cargo from the ships and load it onto railroad cars. Also note the marina and the oil tanks. (Space Imaging)

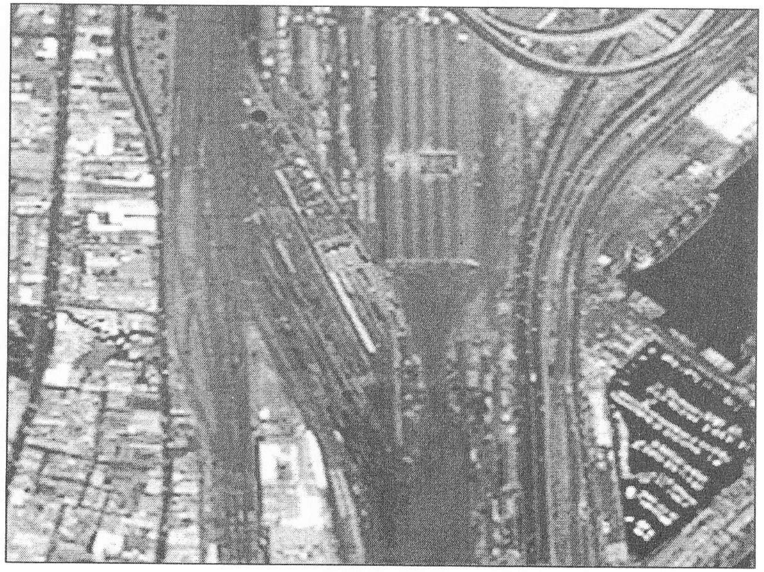

Figure 5.36
Rail terminal at Cape Town's port. Rail lines are obvious because they have much wider turns than roads. (Space Imaging)